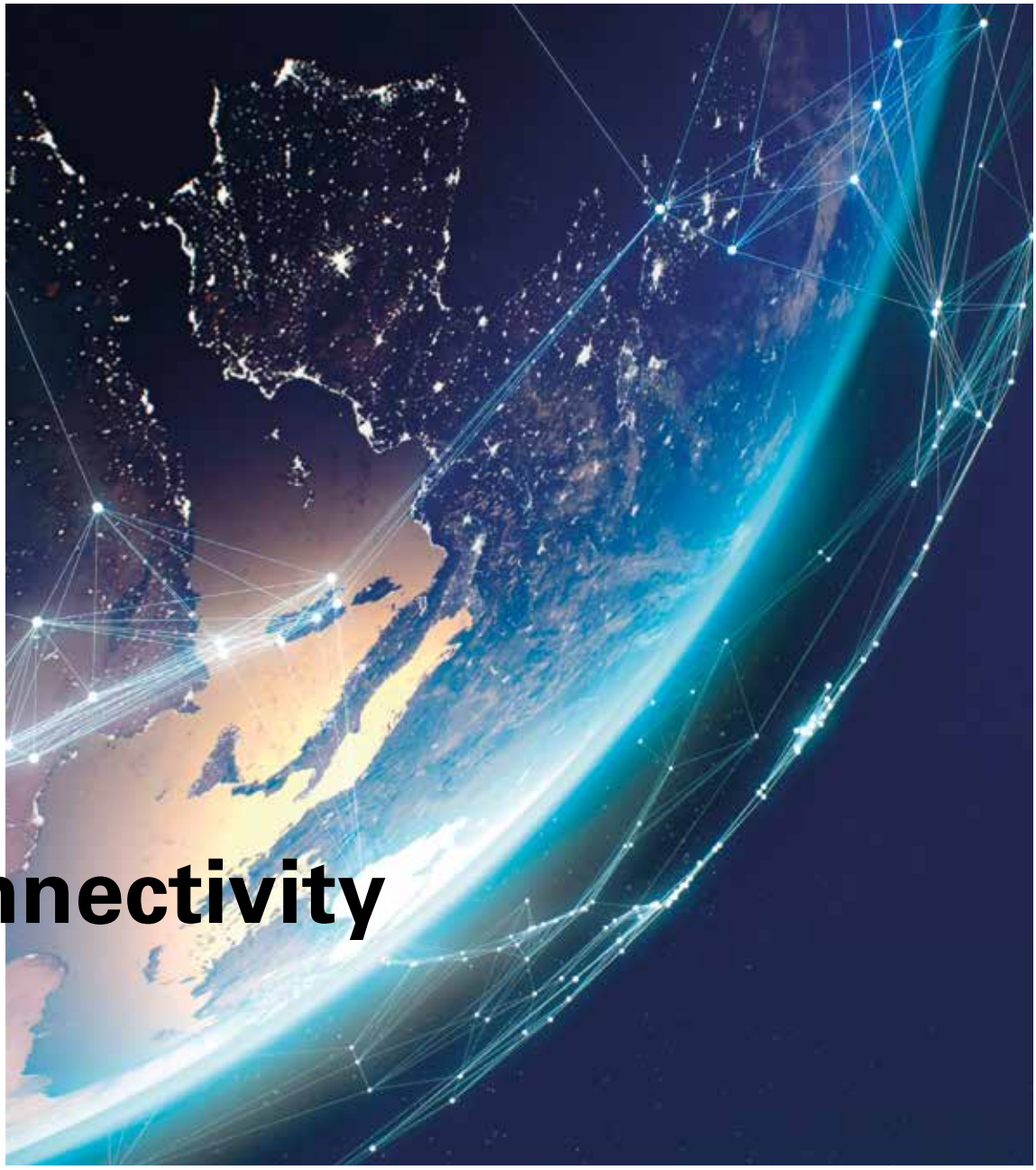
Universität Stuttgart

Forschung Leben

October
2022



Connectivity

Software defined
production and mobility networking

Small satellites
Shooting stars of space travel

Human and robot
New collaboration on construction sites

Prof. Wolfram Ressel

"Connectivity, the principle of net-working based on digital infrastruc-tures, has become a megatrend and might even already be the new normal."

Dear Reader,

Photo: Matthias Schmiedel

Prof. Wolfram Ressel
Rector of the University of Stuttgart

Our lives are currently being revolutionized by digitalization, which now permeates all areas from science and industry to society and connects people and technologies. It is changing socio-cultural values and giving rise to new lifestyles, patterns of behavior, and business models and none of us can circumvent it. Connectivity, the principle of networking based on digital infrastructures, has become a megatrend and might even already be the new normal.

The University of Stuttgart's vision of "intelligent systems for a sustainable society" is also based on connectivity as a key criterion. The principle of networked faculties, collaboration between complementary disciplines through the integration of engineering, natural sciences, the humanities, and the social sciences, is anchored in our mission statement under the term the Stuttgarter Weg (Stuttgart Way).

So there are many good reasons to focus this issue of our magazine »forschung leben« on connectivity. Allow yourself to be transported to cyber-physical worlds in which production and mobility are networked and made more flexible in a "software-defined" manner, and to experience ideas for completely new products with novel functions. Discover how our visionary Prof. Sabine Klinkner is pushing the development of small satellites, without which neither climate research, networked mobility, nor modern communications would be possible and read our interview with the head of Bosch Research, Dr. Thomas Kropf, in which he explains how artificial intelligence is changing industry and how companies and universities benefit from greater collaboration.

I hope you'll enjoy this fascinating edition.
Yours sincerely,

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"We are becoming visible at the European level" The University of Stuttgart is part of the European ELLIS network. **p. 76**

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Shared passion for smart buildings Ilche Georgievski and his PhD supervisor Marco Aiello wish to make buildings smart and sustainable. **p. 82**

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INTERFACE

When humans and robots collaborate

Photos: IntCDC/Christoph Zechmeister, Sven Cichowicz
Title: 2021 Frame Stock Footage/Shutterstock

VISIONARY

Always at the limit

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EXPERIENCE RESEARCH

When software rules

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NOTE PAD

AWARDS

THREE NEW ERC GRANTS

No less than three researchers from the University of Stuttgart have been awarded a prestigious grant from the European Research Council (ERC) since this spring as did

PROF. OLIVER RÖHRLE, Director at the Institute for Modelling and Simulation of Biomechanical Systems and Head of Research at the Cluster of Excellence Data-Integrated Simulation Science (SimTech). His “qMOTION” project aims to use quantum technologies to decipher neuromuscular activation during a movement by focusing on the construction of a so-called high-density magnetomyographic (HD-MMG) measurement system, i.e., a measurement system comprising a grid-like array of up to 100 sensors, which would appear to be particularly promising for deciphering the neuromuscular activity that occurs during bodily movements. In addition to enabling new training and rehabilitation approaches, the project is expected to open up completely new diagnostic and treatment opportunities in the medical field. Röhrle has already received his second ERC grant as well as an ERC proof-of-concept grant.

In his project "DDME- Designing Democracy on 'Mars' and 'Earth'", **PROF. ANDRÉ BÄCHTIGER**, who was the first social scientist at the University of Stuttgart to receive an ERC Advanced Grant, is looking into the future of democracy, its values, and its institutional architectures, whereby he will be relying on an experimental, co-creative, and deliberative design. Members of public from Germany, the USA and India have been selected to take part in online discussions with democracy experts on democratic values and the design of democratic institutions and have been allocated to either a Mars group or an Earth group, the point being that the Mars group will be tasked with designing a democracy for the red planet, while the Earth group will be doing the same in the context of their own countries.

DR. TIAN QIU of the Institute of Physical Chemistry and research group leader in the Cyber Valley Initiative received an ERC Starting Grant. The objective of his VIBEBOT project is to develop microrobots that are able to move through biological tissues to enable minimally invasive medical treatments.

Photos: Private, Visual, Sven Cichowicz

OUTSTANDING DISSERTATIONS

Mathematical thinking + practical sense = new fields of application. This was the "formula" adopted by **Dr. Renate Sachse**, who completed her dissertation entitled "Variational Motion Design for Adaptive Structures" at the Institute for Structural Mechanics (under the supervision of Prof. Manfred Bischof), an outstanding piece of work, for which she received the Daimler and Benz Foundation's Bertha Benz Prize, worth 10,000 euros. Based on the findings of her dissertation, it is possible to easily calculate movements of changeable structures that provide greater energy efficiency and sustainability in the industrial sector.

Europe's best dissertation in the field of systems and control engineering was written by **Dr. Johannes Köhler**, whose work garnered him the European Systems & Control PhD Thesis Award 2021. Köhler wrote his thesis, "Analysis and design of MPC frameworks for dynamic operation of nonlinear constrained systems," under the supervision of Prof. Frank Allgöwer at the Institute for Systems Theory and Automatic Control (IST).

THE PRIMA PRIZE FOR TOP FEMALE GRADUATES

The University of Stuttgart's Prima Prize, which is endowed with 1,000 euros, is awarded in recognition of outstanding final theses by female graduates of the University. It was originally created to mark the 100th anniversary of the first female graduate – chemist Nora Kräutle – at the Stuttgart University of Technology. This year, the award was given to two female scientists from Faculty 8: **Annika Belz**, whose master's thesis in physics was described as an outstanding, independent work by an exceptional talent, and **Jessica Renz**, whose master's thesis in mathematics received special praise for its interdisciplinary collaboration with the biological sciences and the wide range of topics covered. The award ceremony was held at the University of Stuttgart during this year's Research Day.

Photos: Daimler and Benz Foundation/Senger, Lisa Jöchler

STRONG SEASON FOR THE FORMULA STUDENT TEAMS

An extraordinary racing season for the University of Stuttgart's Formula Student teams culminated in a double victory at the Red Bull Ring in Austria in early August: the racing team won the overall standings in the combustion engine class, while the GreenTeam took the top spot on the podium in the electric class. Both teams had to compete in eight events in their respective classes. The students' knowledge is assessed in the three static disciplines (Business Plan Presentation, Engineering Design Event, and Cost & Manufacturing Event), which involve financial planning, cost accounting, business planning, and general engineering skills in addition to specific engineering skills relating to the purpose-built racing cars. The cars are tested for handling, acceleration, driving dynamics and efficiency in five dynamic disciplines (SkidPad, Acceleration, Autocross, Endurance, and Efficiency).

These victories in Austria were just one more milestone in a whole chain of successes. Back in July, for example, the racing team was able to secure a first-place finish at Formula Student in the Netherlands and also took third place at Formula Student East at the Hungaroring in Hungary. Meanwhile, the GreenTeam won its "home game" at the Hockenheimring and came third in the Netherlands.

EXCELLENT RANKING RESULTS

The University of Stuttgart performed extremely well in the Shanghai Ranking's current **Global Ranking of Academic Subjects (GRAS)**, particularly in the engineering sciences, and ranks among the world's top 150 universities in this field with a total of four subjects. Two subjects, Mechanical Engineering and Civil Engineering, were ranked 51-75, placing them among the top 75 worldwide. Automation & Control and Water Resources were also ranked in the top 150 (101-150). The University of Stuttgart achieved 1st place in Civil Engineering in a national comparison.

For the first time, the University of Stuttgart was ranked among the top 25 percent worldwide in the **QS World University Ranking 2023**, having been ranked 355 out of a total of 1,422 listed universities. These good results are due, among other things, to the ratings given for "citations per researcher" and "international students".

U-Multirank 2022 ranked the University of Stuttgart highly for its excellent research and technology transfer: having garnered a total of 12 top ratings (Group A), ours is one of the "Top Performing Universities in Germany," and individual subjects such as physics, process engineering, and computer science also scored very highly.

Photos: Maximilian Partenfelder

NEW HONORARY SENATORS

Eberhard Hinderer, Martin Litschel and Dr. Helmut Schelling, founders of Vector Informatik GmbH as well as benefactors and members of the board of trustees of the Vector Foundation have been appointed as honorary senators of the University of Stuttgart. At the award ceremony Rector Prof. Wolfram Ressel paid tribute to their non-material and material support for the University of Stuttgart, their many years of personal commitment, and their exemplary achievements: “Eberhard Hinderer, Martin Litschel, and Dr. Helmut Schelling have remained closely connected to the University of Stuttgart and their alma mater. As founders and managing directors of the innovative company Vector Informatik GmbH and now as benefactors and members of the board of trustees of the Vector Foundation, they have been doing exemplary work for many years. (…) The appointment of these three dedicated men as honorary senators is the University of Stuttgart’s way of honoring their achievements and showing our gratitude for their outstanding commitment to our university”.

2:8

Two out of eight new priority programs approved by the Senate of the German Research Foundation (DFG) this year will be established at the University of Stuttgart: together with various partners, Prof. Mathias Liewald of the Institute for Metal Forming Technology (IFU) hopes to extend the established finite element method for designing forming dies and processes through the addition of data-driven modeling. Along with the research group, which he coordinates, Prof. Christian Rohde of the Institute of Applied Analysis and Numerical Simulation (IANS) is planning to mathematically substantiate various hypotheses in the field of fluid mechanics and to develop a new generation of numerical simulation tools.

Photo: Alwin Maigler

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München m@wtr-architekten.de **Basel** bs@wtr-architekten.ch

See here for a video about current research into porous media.

PEERING INTO POROUS MEDIA

The University of Stuttgart's Porous Media Lab (PML) has been housed in a clustered location on the Vaihingen campus since the summer of 2022. X-ray tomographic and microfluidic studies can be carried out there to help visualize and understand the invisible flow and transport processes as well as the deformation behavior that occur in porous media, such as those that take place inside a lump of concrete and the behavior of oil-water mixtures underground. A core element of the PLM is the XRCT Lab, which is an X-ray tomography device developed in-house, which creates 3D images from non-transparent materials and enables researchers to gain high-resolution insights into phenomena at the pore scale. The second core element of the PML is the Microfluidic Lab, where synthetic porous materials can be created.

The PML is a central experimental platform, which is used by both the “Data-Integrated Simulation Science” (EXC 2075, SimTech) Cluster of Excellence and the Collaborative Research Center for Interface-Driven Multi-Field Processes in Porous Media. Flow, Transport and Deformation” (SFB 1313) at the University of Stuttgart. As a “shared lab”, it is also available to visiting scientists from Germany and abroad.

NEW BIOENGINEERING BUILDING

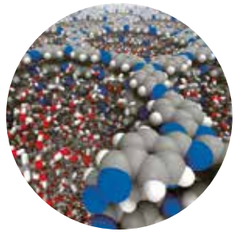
The winners of the design competition for the new bioengineering building on the University of Stuttgart’s Vaihingen Campus have been chosen. The 1st prize was awarded for the design by kleyer.koblitz.letzel.freivogel Gesellschaft von Architekten mbH, Berlin. The various bioengineering institutes, which are currently spread across the two campuses in Vaihingen and the city center, can now be brought together under one roof in the new building, which also represents an important milestone on the way to renovating the University of Stuttgart’s Natural Sciences Center (NWZ). Having been in use for almost 50 years, there is an urgent need to renovate the two buildings, but this cannot be carried out during ongoing operations. In the first step, the majority of the users of the NWZ II are therefore to be housed in alternative buildings so that the NWZ building can be completely renovated and then reoccupied.

Photos: Uli Regenscheit, BÄUMLE Architects/Urban Planners

10 FAIRY-TALE YEARS FOR THE SUPER PROGRAM

Since 2012 the University of Stuttgart’s short-term SUPER research program has been promoting internationalization and bringing research to life. Since its inception, the program, which began with three students from the Massachusetts Institute of Technology (MIT) and the University of Toronto, has grown over the years to include up to 20 participants and currently includes collaborations with the University of Arizona, Purdue University, and the University of British Columbia. In return, exchange placement are made available to University of Stuttgart students at selected partner universities.

The program attracted nine students from North America to Stuttgart this summer, including biomedical engineering student Hasina Shir from Arizona, who assisted a doctoral researcher at the Institute of Applied Optics (ITO) with her research into an infection early warning system based on the use of optical methods to detect bacteria and viruses.



CATALYSIS COLLABORATIVE RESEARCH CENTER ENTERS SECOND ROUND

The German Research Foundation (DFG) has approved a second funding period for the University of Stuttgart's "Molecular Heterogeneous Catalysis in Defined Directing Geometries" Collaborative Research Center (SFB 1333), which will receive nearly 12 million euros in funding. 19 research groups from the University of Stuttgart are collaborating at the SFB with partners from the Max Planck Institute for Solid State Research and the Universities of Paderborn, Marburg, and Bochum to conduct research into hybrid catalyst systems that enable more efficient chemical-catalytic production processes or may even open up completely novel reaction pathways. Prof. Oliver Sawodny of the University of Stuttgart's Institute of Polymer Chemistry (IPOC) is the current spokesman of the SFB.

Photos: Lydia Lehman, University of Stuttgart/SFB1333

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Photo: University of Stuttgart , IFB Team Inferno

FIREFIGHTING AIRCRAFT "INFERNO" WINS DLR DESIGN CHALLENGE

Large areas of forest are burning in Spain, France, and the Elbe Sandstone Mountains in the heat-wave summer of 2022. Firefighting aircraft or helicopters fires are often used to control wildfires from the air. A team from the University of Stuttgart's Aerospace Engineering study program has now presented a concept for a hybrid firefighting aircraft named "Inferno" that combines the speed and efficiency of an airplane with the flexibility of a helicopter, a design for which the team was awarded this year's German Aerospace Center (DLR) Design Challenge. The design combines two aircraft propellers for forward flight with eight propellers for vertical flight, which enables the aircraft to take on water even at small water stations and to discharge it in a very targeted manner over the source of a fire.

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Wir haben Ideen, wir haben zu tun, wir haben Spaß – und wir suchen Dich!

3 QUESTIONS FOR

MATTHIAS SCHNEIDER

Head of SmartLab, Group Leader Wood and Composites Processing

"SmartLab" is the name chosen by Matthias Schneider and his team for their advanced wood laboratory at the Institute for Machine Tools (IfW), which serves as a proving ground where industry representatives and students can work with and process timber. The facility is equipped like a small factory with saws, throughput plant, CNC machining centers, and a chipping robot all supported by augmented reality (AR) and the Internet of Things (IoT).

What makes the wood lab a SmartLab?

The machines in our laboratory think for themselves and alert us to any errors. We operate the machines with the aid of technology, which enables us to work more efficiently and cost-effectively. What is special about this is that we are implementing the new technologies on the existing machinery. In practical terms, we overlay a network of sensors over the respective machine tool without interfering with it or modifying it meaning that it retains its certification status, which saves time and costs.

What do the new technologies specifically enable you to do?

We use augmented reality applications to store information, such as instruction steps, product data sheets, and status or error messages, in each of a machine's sensors. All the users have to do is point a tablet at the sensor and the information is displayed on the screen, which for example, can provide them with step-by-step instructions for presetting tools. We also created an IoT platform for monitoring wood dust in the SmartLab, as wood dust can cause serious health problems for employees, which is why we installed particulate matter sensors in the laboratory, which display the measured values on a monitor in the entrance area.

What challenges do you still have to overcome?

One challenging aspect is that, unfortunately, many systems are not currently compatible with all the machinery, so we have to develop numerous special solutions to integrate the smart technology into the machines in question, which is obviously expensive and time-consuming. Our aim is to develop more plug-and-play solutions to address this issue. We also want to increase the acceptance of digitalization and new technologies in the skilled trade departments of smaller companies to which end we need to calculate the benefits of digitalization for smaller businesses to be able to justify the time necessary to prepare and maintain the data.

See here for a video about the digital wood lab.

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Photo: University of Stuttgart/IfW

Enthusiastic about space research from an early age: Prof. Sabine Klinkner has held the Chair of Satellite Technology at the University of Stuttgart since 2015.

Always at the Limit

TEXT: Jutta Witte
PHOTOS: Sven Cichowicz

Small satellites are the shooting stars of space travel and are at the center of Prof. Sabine Klinkner's research and teaching. She and her team are advancing the development of these smaller systems without which such things as climate research, networked mobility, and modern communications would no longer be possible.

"It's crazy that you can study something like this: it's usually the preserve of NASA!" That's what Sabine Klinkner thought when she came across the "Aerospace" folder at the Vocational and Information Center. Having good grades in maths and physics and following a few taster lectures, she began her engineering studies at the University of Stuttgart in 1996. "Even now", she says "I'm still thrilled about the fact that we always have to go to the limits in aerospace research and are continuously faced with new challenges." After all, satellites cannot be built using the modular design principle. A satellite is a highly complex system that has to get by on extremely limited resources both in terms of the construction materials and energy consumption whilst meeting some extremely demanding specifications. Above all, it has to be robust. Although the ground crew can upload software updates once the satellite is in orbit, for example in connection with the mission program, nobody can press the reset button. Klinkner always sees satellite research as an adventure.

Following her studies, she first worked for twelve years in a medium-sized systems aerospace products company, where she built scientific instruments and rover systems, such as robots that are used to explore the surface of planets, before committing to a career in science and also worked on her part-time doctoral degree studies. In 2015, she was invited to accept the University of Stuttgart's newly created Chair of Satellite Technology, which she ultimately accepted in order to have more freedom to pursue her scientific work. Klinkner introduced exploration robotics to the University and began to promote the development of small satellites, "which are not only needed in all aspects of spaceflight, but are also the perfect subject for teaching." →

→ That is why she is a dedicated advocate of "a well founded, highly qualified and practice-oriented education." Power and communications systems, data management and thermal regulation, and the propulsion system are just some of the satellite's subsystems, whose interaction in orbit have to be orchestrated under difficult conditions. Klinkner involves her students in the development process as early as possible. "To understand these processes, you have to go through all the stages yourself," she explains. One example is the "Flying Laptop", which was launched into space from the Baikonur Cosmodrome on board a Soyuz-2 rocket in the summer of 2017 and was developed, built, and qualified for use in orbit almost exclusively by students and doctoral candidates. The fact that it is still orbiting 600 kilometers above the Earth is a success story for all involved.

MISSION ROMEO: INTO SPACE WITH INNOVATIVE TECHNOLOGY

As is the case for about 95 percent of small satellites, the "Flying Laptop" is traveling in a low Earth orbit (LEO). Klinkner's wants to reach medium earth orbit (MEO) in 2025 with her new "Research and Observation in Medium Earth Orbit" (ROMEO) mission. MEO extends to an altitude of 36,000 kilometers above the Earth and, until now, has been relatively underutilized: even getting there presents a challenge, as does operating a satellite in that zone. Currently, our knowledge about the environmental conditions in the MEO and their effects on materials and technology remains limited. That is why the new 60 kilogram "lightweight" research satellite will not only carry out Earth observations and space weather research, but will also take innovative technologies into space to be tested. The research team wants to find out how they behave in a region of outer space, which is exposed to extreme radiation, and how they can be made fit for future MEO satellite missions.

Alongside a green hydrogen propulsion system and a radiation-tolerant central computer, which the team is planning to assemble using "off-the-shelf" components for the first time, a compact and lightweight communications system with the lowest possible power requirements for data transmission in the amateur X-band will also be on board. "The most power-hungry component in a small satellite is the communications system," Klinkner explains. Signals transmitted between the satellite and the ground station are repeatedly disrupted due to various transmission losses. Until now, communication systems have been designed conventionally, i.e., to cater for the worst-case scenario, to ensure that they always function reliably, which, however, not only increases the energy requirement but also has a negative effect on the data transmission rate.

RESEARCH SATELLITE TO REACH AN ALTITUDE OF 2000 KILOMETERS

The new system is expected to automatically adapt to the continuously changing conditions during a satellite overflight in order to save resources and optimize the use of bandwidth, an adaptive capacity, which Klinkner finds "particularly interesting" in view of the ROMEO mission because the plan is for the research satellite to spiral up from a low, circular orbit to a medium, elliptical orbit at an altitude of up to 2,000 kilometers after three months. If, rather than orbiting the Earth in a circle, a satellite takes an elliptical course, the environmental conditions become even more volatile, which significantly alters the requirements for a communications system that needs to be perfectly tuned. In view of this unique challenge, ROMEO is the ideal mission for →

95%

Approximately 95 percent of small satellites are in Low Earth Orbit.

Prof. Dr Sabine Klinkner

"What really fascinates me is to see the things I build fly."

A booming market: There is a global demand for small satellites. Prof. Klinkner and her team are working on the further development of these little technological wonders.

→ testing an adaptive data transmission technology. The AI-controlled ground station will determine and transmit the optimal data transmission signal coding for each point in time in order to optimize the use of the entire overflight for data collection purposes. "That will enable us to get the most out of the mission," says Klinkner, who is expecting to increase data transmission rates by up to 100 percent.

Her research projects place her at the interface of an expanding market in which the small satellite industry is being driven by both digital companies and the legacy economy. These smaller satellites have long been a "key component" for the Federation of German Industries (BDI) and the Association of German Engineers (VDI) and will account for 90 percent of the approximately 15,000 satellites to be launched by 2030 according to the two organizations. What is the role of the scientific community in light of this boom? "Our role is to explore new ideas without the pressure of commercial imperatives, which will later benefit everyone," Klinkner explains: "And we can also make significant contributions towards solving urgent problems such as the avoidance and removal of space debris."

Trying to find ways of ensuring sustainability and safety in space given the growing volume of orbiting traffic is just one of the exciting challenges that space researchers are likely to face going forward. As Klinkner explains in summary: "We need to develop technologies that will keep the existing orbital zones clean even as we open up new ones." Notwithstanding her thirst for adventure, the mother of two has not yet booked a ticket to space. "What really fascinates me," she says, "is to see the things I build fly. And that's by no means a given in the aerospace sector." ↠

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MORE POWER LESS WEIGHT

TEXT: Michael Vogel

Lighter satellites thanks to new technology: the use of perovskite solar cells in space exploration is a recent field of research with great potential.

A high-speed data line via cable or mobile communication systems is not available to everyone in the world. Yet where this is the case, satellites can provide a broadband Internet connection. Elon Musk's Starlink is the best-known example of this approach. Most modern satellites are powered by solar cells, whereby the greater their efficiency and the more durable they are, the longer a satellite can remain active. The University of Stuttgart's Institute for Photovoltaics (IPV) and Institute of Space Systems (IRS) are conducting research on solar cells that have the potential to make satellite operations more cost-effective.

As engineer Dr. Claudiu Mortan, a researcher at the IPV, explains: "The solar cells used in current satellites are based on gallium arsenide, not silicon like the photovoltaic modules installed on rooftops. This semiconductor material has been shown to be much more robust in the extreme conditions of outer space." However, another class of compounds, known as the perovskites, could prove to be even more suitable in the future and are already being used for terrestrial solar cells as an alternative or complement to silicon cells. "Perovskites," as Mortan explains, are metal halide compounds." Dieter Weber of the University of Stuttgart's Institute of Inorganic Chemistry published the first paper on perovskites back in 1978." →

Dr. Claudiu Mortan

"Solar cells in are exposed to extreme conditions in space that cause them to age faster than they do on Earth."

→ This was followed by the first scientific publication on a perovskite solar cell in 2009. "Some 13,000 scientific publications have now been published on the subject," says Mortan, highlighting the enormous increase in interest. IPV head Prof. Michael Saliba is one of the world's most cited researchers in the field. "By contrast," Mortan says, "only around 40 papers have been published on perovskite solar cells for use in space." The IPV and IRS launched the PÆROSPACE project to dedicate themselves to this subfield.

FUNDED BY THE "TERRA INCOGNITA" PROGRAM

The IPV received 50,000 euros of start-up funding for this purpose in 2022 through the University of Stuttgart's "Terra incognita" research funding program, which is intended to help develop previously undefined research fields using interdisciplinary approaches and to facilitate pioneering research.

Current solar cells made of semiconductor materials are produced on wafers in a complex and therefore expensive manufacturing process. The use of perovskites, on the other hand, is much simpler as they can be painted onto a substrate as a solution, after which the solvent evaporates leaving behind the desired layer. The active layer of perovskite cells is much thinner than that of cells made of semiconductor materials, which, as Mortan explains: "has a positive effect on the weight-specific electrical output." "Whereas conventional solar cells made of gallium arsenide can only produce three watts per gram, perovskite solar cells can achieve 30 watts per gram." The lower a satellite's weight, the less expensive it is to launch.

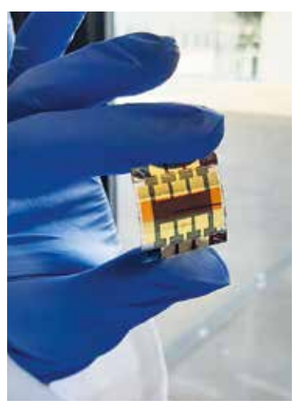
"Another benefit is that perovskite solar cells can easily be applied to films or foils," Mortan says and these can be rolled up. The upshot is that a satellite equipped with perovskite cells would not only be lighter, but would also have smaller dimensions at launch. Gallium arsenide solar modules are too thick to roll up and can only be folded and hence require much more space.

The objective of the PÆROSPACE project is to find suitable perovskite solar cells for use in space. "However," as Mortan further explains, "solar cells in are exposed to extreme conditions in space that cause them to age faster than they do on Earth." On the one hand, temperatures can fluctuate greatly, from minus 50 degrees Celsius in the Earth's shadow to 150 degrees Celsius in direct sunlight and any satellite orbiting at a similar altitude to the International Space Station experiences this temperature change every one and a half hours, which can cause cracking in the cell. On the other hand, the vacuum in space could cause unwanted outgassing of atoms from the cell, which would impair its function. And, last but not least, solar cells can be hit by energetic particles, e.g., from the sun, resulting in a deterioration of their optoelectronic properties. For all of these reasons, perovskite solar cells must first be qualified for use in space.

Mortan's team is working on a housing whose surface area is about the size of two smartphones placed side by side, which will contain four perovskite solar cells produced at the IPV, each a few square centimeters in size, which are to be tested in a stratospheric balloon at an altitude of 35 kilometers, where whilst the prevailing conditions are not the same as in outer space, they are much more extreme than on Earth. The balloon will be launched by KSat, the University of Stuttgart's Student-based Small Satellites Group. During the several-hour-long flight, Mortan's team will record changes in the characteristic properties of the four cells.

Overlapping with this balloon-based experiment, preparations for a satellite test of perovskite cells are being made in collaboration with the IRS. The funding application has already been submitted. A small satellite will be launched into a 2,500-kilometer orbit in 2025 to test the IPV's perovskite solar cells under space conditions for at least a year. "As yet," Mortan explains, "no such long-term analytical data is available." ⇥

A cost-effective energy source: Future satellites to be supplied with energy from flexible perovskite solar cells.



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Photos: Shutterstock/3Dsculptor, IPV/Tobias Heim

When humans and robots collaborate

The IntCDC's robotic platform: a laboratory for future construction sites

Photos: IntCDC/Christoph Zechmeister, Uli Regenscheit

TEXT: Daniel Völpel

An autonomous crane delivers a construction element, a robot accepts it, positions it and bolts it together: this is the vision being worked on by an interdisciplinary team at the University of Stuttgart's "Integrative Computational Design and Construction for Architecture" Cluster of Excellence (IntCDC). Social scientists are concurrently looking into how people and machines could best collaborate on construction sites.

Prof. Oliver Sawodny

"Introducing this level of automation will make constructions sites much more complex."

Prof. Sawodny and his team converted a 40-meter-high crane for their research.

For many years now, machines have been handling some of the work on construction sites, yet humans will continue to play a central role there – sociologist Prof. Cordula Kropp, Head of Department at the University of Stuttgart's Chair of Sociology of Technology, Risk and Environment, whose primary focus is on risk and technological research, refers to this as a "human-machine configuration." "This is something we will eventually have to come to terms with in all areas, including, for example, autonomous mobility." Looking specifically at this human-machine configuration as it plays out on constructions sites, Kropp explains that: "Until now, the fact that by its very nature, a construction site is a social construct has been ignored."

One fundamental question for Kropp is: "At what point can we really place trust in such a configuration?" Buildings are expected to last at least 50 to 100 years. "With this in mind, it's really important to develop systems that don't make us think: 'It's automated and we humans no longer have anything to do with it.'" What we need, Kropp explains, are systems "which still enable construction workers to be responsible for guaranteeing this high quality." Which, she continues, is why it is important to design cyber-physical production systems that are so reliable that even when you enter a partially automated building in the future, you will still be able to blindly trust in its stability.

SPECIAL CRANES FOR CONSTRUCTION AUTOMATION

The social scientist is specifically addressing such questions at the University of Stuttgart in a collaborative project with teams led by Prof. Oliver Sawodny of the Institute for System Dynamics (ISYS) and Prof. Uwe Sörgel of the Institute for Photogrammetry (ifp). Engineers at the "Integrative Computational Design and Construction for Architecture" cluster of excellence (IntCDC, spokesman Prof. Achim Menges) have been working for three years on automating the delivery and assembly of construction elements on building sites and have converted a 40-meter tower crane with a 60-meter jib to this end. Every time the crane moves, overlapping cameras on the jib update the digital model of the construction site. The crane can autonomously travel along defined paths while carrying a load of up to five tons, Sawodny, an expert in large-scale robotics, explains, and can currently follow these routes with an accuracy of plus/minus ten centimeters. "That's quite a feat given the size of the work area," he adds.

But the load is suspended on a cable and is therefore susceptible to the wind, for example, which is why the component has to be precisely fitted by a second robot on the ground, which is why the team developed a novel control system for a mini mobile caterpillar-type →

Sociologist Cordula Kropp's focus is on the role of people on automated construction sites.

Prof. Cordula Kropp

"Until now, the fact that by its very nature, a construction site is a social construct has been ignored."

→ crane. The University of Stuttgart's Institute of Engineering Geodesy (IIGS) provided support in the form of robotic tacheometers,→ which enable the crawler crane to orient itself so precisely spatially that it can position the load to within a few millimeters. The team is currently focusing on developing the necessary effectors, i.e., the tools located at the end of the jib that allow the load to be moved, gripped or bolted in a targeted manner.

Once these effectors are operational and the two cranes are coordinated, they will be able to install the robotically prefabricated elements. The elements will be manufactured at the IntCDC's new flagship facility, the Large-Scale Construction Robotics Laboratory (LCRL), which was completed in the spring of 2022 with two large-scale robots each for timber structures and large-scale fiber composite components, where the cranes are also located. All of the machines, including the large robots, are mobile and "can be deployed via containers and assembled at the construction site, where they will manage the prefabrication tasks, which will then be installed by our systems," Sawodny explains.

AI WILL PLAY A CENTRAL ROLE ON FUTURE CONSTRUCTION SITES

However, as the researcher points out, what sounds like a simplification poses an enormous challenge to all those involved: "Introducing this level of automation will make constructions sites much more complex." An IntCDC structure will then first be designed and planned as an complete system on the computer, which will use artificial intelligence applications to develop the individual components in the optimum shape in order to save material and achieve maximum strength. after which it will create the master files, which will be transferred to the production robot. The robot will then work semi-autonomously to construct timber or fiber composite elements, which will then be passed on to the tower crane and lifted into position. The tracked crane will then pick them up and bolt them in the correct position.

The fact that human workers will continue to work on, plan, and monitor the construction site at the same time raises new questions for Sawodny such as: "What → user interfaces need to be incorporated? What kind of data will we be able to retrieve? And what is the best way to design the interfaces between the individual modules needed to handle everything from task and route planning to trajectory generation to data transfer to the machine?

5 t

The crane can autonomously travel along defined paths while carrying a load of up to five tons.

This is where the social scientists come back into play. "At that point, the machines will have to interoperate with each other, and the people will have to interact with both the interoperating cranes and the data," Kropp explains: That's what we refer to as the interobjectivity of a complex configuration in which everything has to communicate with everything else for it to function properly." Because the machines may initially only be partially automated, she continues, situations may arise in which, for example, a Romanian tower crane operator and a Bulgarian tracked crane operator may be working together using leased machines that have been booked by different companies for just a few weeks. Meanwhile fluctuating weather conditions may well mean that conditions on a construction site change continuously. "If we take this example situation," says Kropp, "we can imagine that both of them may only speak their own native languages, and be working with this particular machinery for the first time, and still have to be able to deal with this inter-networked system, which they may not always understand, with confidence. That presents a major challenge! So the real life situation is far more complicated than anything we've seen so far in cyber-physical systems research, which," she adds, "is why organizational sociology expertise is essential."

FOCUS ON PEOPLE'S NEEDS

The sociologist and her colleague Ann-Kathrin Wortmeier are currently interviewing construction workers and people who work for leasing companies, crane manufacturers, and participants in crane operator training courses to ask what the expectations, problems, and risks are. "We start from human centered design," Kropp explains. "All developments should be based on human requirements and needs. Only then will they be used in an optimal manner, which is why we are also asking crane operators and site foremen about specific issues they have identified."

This has given rise to possible scenarios and criteria lists: How much control capability will future machine operators need? At what point will they be able to place their trust in these machines? "What our previous research and preliminary publications show," Kropp explains, "is that the precise layout of this configuration is crucial." The risks, she adds, would extremely high if people were only there to switch the machinery on and off while it made autonomous decisions based on data. If, on the other hand, the machines were there to support the human workers and they were allowed to make decisions and maintain the machines themselves, "then they would be more confident about intervening in the event of a malfunction in order to reduce the risks." This, in turn, would be an essential prerequisite for creating confidence both among the construction workers in their robotic "colleagues" and among all those who would later use the buildings constructed in this way. ↠

Experts in large-scale robotics: Prof. Sawodny with IntCDC employees

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Photos: Uli Regenscheit

"Trust is rooted in reliability."

Photos: Bosch Research

INTERVIEW: Miriam Hoffmeyer

Prof. Dr. Thomas Kropf, head of Bosch Research since 2018, discusses the ways in which connectivity is shaping our everyday lives, how AI is changing the industrial sector, and how companies and universities benefit from increased collaboration.

What does the megatrend connectivity mean for business and society?

PROF. DR. THOMAS KROPF (TK) Actually, connectivity is no longer a trend as such, but is already creating more convenience, efficiency, and safety in everyday life for a wide range of products and encompasses connections in more than just the technical sense, something which the recent pandemic in particular has highlighted. One of the reasons why the economy remained productive was that people were able to keep in touch both privately and professionally thanks to videoconferencing, social networks, online learning services, and e-commerce platforms.

It has been possible to network all of our electronic products since the beginning of the year. Customers now expect new functions in consumer goods that are only possible when the products are networked. For instance, I love baking bread and find it extremely convenient to be able to preheat the oven while I'm still out and about. Connectivity also plays a key role in the mobility sector – from up-to-date information on traffic jams to driver assistance systems, and automated driving. Whether or not drivers are aware of it, cars are continuously exchanging information with traffic systems and other vehicles. Probably the best example of how connectivity saves lives are the automatic emergency call systems that are mandatory in new vehicles.

But there are also risks associated with networking including malfunctions caused by software glitches, data theft, and manipulation by hackers, which is why many people remain skeptical about it.

TK "Digital Trust" is the keyword in this context: Our quality assurance promise not only applies to the real world, but also to the digital sphere. In addition to functionality, this includes the secure management of data, which can now be collected anonymously. One of our important research focuses is on cyberattack protection. Bosch has developed a set of ethical standards for the application of artificial intelligence (AI), which are taken into account in all product development processes and which stipulate, among other things, that AI must be robust, safe, and understandable, and that no decisions affecting people should ever be made without the involvement of a human being.

How important is artificial intelligence for the development of connected products?

TK They go hand-in-hand! The real-time availability of data is only made possible through connectivity, and, as we know, AI is only as smart as the data and the algorithms we feed it, which means that the full potential of AI can only be realized in a reliable and secure combination with connectivity, which currently plays a central role in almost every area of application in which we carry out our research. In recent years, the Bosch Center for Artificial Intelligence (BCAI), in collaboration with the engineering sciences, has significantly advanced the development of AI applications such as deep learning, computer vision, and natural language processing.

What is the strategic direction of Bosch's connectivity research, and what are your priorities for the next few years?

TK A key focus is on researching and developing solutions for the "factory of tomorrow" based on networking and artificial intelligence. Electronic networking is changing the industrial sector even more than the private sector, where connectivity solutions are already widespread. Not only does the real-time availability of quality, process, and machinery data facilitate more flexible and efficient production processes, it also opens the door to completely new business models. We are currently collaborating with several partners from the industrial sector as well as the University of Stuttgart on the "Software-Defined Manufacturing for the Automotive and Supplier Industry" (SDM4FZI) project . One focus of our research is on the construction of a production station using a standardized basic frame and variable modules, which will make it possible to adapt the production →

→ system's hardware to changing requirements. We are also researching the development of an "engineering toolchain", which is a software toolbox for simplifying and expediting the redesign of production systems.

In addition to AI and robotics, another important research area for Bosch Research is the "Internet of Things" (IoT) in relation to connected household appliances, tools, smart home services, and energy management. Modern energy systems would be inconceivable in the absence of networking: photovoltaic systems are connected to battery storage units, which are in turn used to charge electric cars; smart, energy-efficient, heating systems are controlled by sensors and learning algorithms. A particularly clear example of how networking in the form of sector coupling can make a significant contribution to sustainability concerns energy management. →

PROF. DR. THOMAS KROPF

"We are always interested in research collaborations with universities on all of these subjects, as this is where basic research meets practical applicability"

Prof. Dr. Thomas Kropf has headed up the Research and Advance Engineering Division at Robert Bosch GmbH since July 2018. He joined the Bosch Group in 1999 and, prior to his current position, was responsible for systems development for the automotive sector, among other things. Kropf studied electrical engineering and earned his doctorate and habilitation in computer science. In addition to his work at Bosch, he currently teaches computer science at the University of Tübingen.

→ We are always interested in research collaborations with universities on all of these subjects, as this is where basic research meets practical applicability. Both parties find it highly beneficial to conduct joint research based on real-world application data.

From your perspective, what should universities be doing to address the challenges of connectivity?
TK Although universities succeeded in making the digital transition quickly and well during the pandemic, I don't think enough attention is being paid to the opportunities it presents: they shouldn't just be reverting back to earlier teaching models. I'm a big fan of the "flipped classroom" concept, in which students study theoretical concepts at home and then come together at the university to apply what they've learned.

What would make collaboration with universities easier from your perspective?
TK The regulations relating to the protection of intellectual property are a major hurdle. The IP regulations in Germany are such that collaborations with universities are often not worthwhile for businesses. They also make it more difficult to set up spin-off companies and discourage investors. The IP regulations in the USA, by contrast, are much more favorable for university spin-offs and business enterprises. Germany is its own worst enemy in this respect! I would also welcome more permeability between universities and industry: it would be wonderful if more researchers, particularly post-docs, would take the opportunity to conduct research while working for a company for one or two years. Students should engage in project work even earlier and to a greater extent, and in as interdisciplinary and international a way as possible, which reflects the reality of industrial research and development.

Bosch has been collaborating with the University of Stuttgart for over 80 years.
TK Yes, and this collaboration works very well! Bosch is a sponsor member of Arena 2036, and a new collaboration in quantum sensor technology was also established this year. In addition to SDM4FZI, we are participating in another major joint project relating to connectivity known as the Software-Defined Car (SofDCar) project (for both projects, see pp. 28-35). Being so heavily involved in research collaborations also enables us to recruit excellent specialists: the majority of the graduates in technical subjects that we at Bosch recruit throughout Germany come from the University of Stuttgart.

Bosch Research and the University of Stuttgart will be hosting "Inventing the Future," in late October, a joint event on futuristic topics related to connectivity and AI. What do you see as the benefits of an even closer strategic collaboration?
TK Trust is rooted in reliability. A whole range of issues can be better resolved if strategic road maps are put in place to ensure that collaboration goes beyond individual projects strung together. Planning is also easier when both parties know that they have a reliable partner with a similar interest in certain research topics. And finally, collaborations with a high public profile could potentially reduce the mistrust of university-business collaborations, which is unfortunately still widespread among the general public, despite the fact that they are crucial for the innovation cycle. Economic structures, processes, and development time frames from industrial research can further increase the efficiency of university research. And if stakeholders in the industrial sector are able to conduct research and work more productively with the help of the knowledge generated by the academic research community, this will also benefit university research through the taxes they pay. →|

Further information on the "Inventing the Future" event organized by Bosch and the University of Stuttgart.

When software rules

The car as a research focus: researchers in Stuttgart are working on using software solutions to bring about sustainable change in car production.

TEXT: Andrea Mayer-Grenu
PHOTOS: Sven Cichowicz

Two major projects at the University of Stuttgart are advancing the networking of production and vehicles.

Whether it relates to cars, factory floors, networks, or entire cyber systems, the term "software-defined" is currently on everyone's lips. but what it actually means is open to a wide variety of definitions, and the debate on the subject almost takes on philosophical dimensions. Prof. Alexander Verl, head of the University of Stuttgart's Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW), uses the term "software-adjustable" to describe the basic concept. "In future," he says, "factories will have to become more flexible to enable companies to respond quickly to new products, changing production volumes, and uncertainties in the supply chain network. Going forward," he adds, "these adjustments will largely be made via the software, so that there will be little or no need to change the hardware, i.e., the machinery."

"The way I see it," says Prof. Michael Weyrich, head of the Institute of Industrial Automation and Software Engineering (IAS), "we need to go much further than that: rather than simply using software to configure systems, our goal is to create entirely new interconnected systems. Software creates a parallel world to the mechanical world, a world of information in which data and rules can be interchanged and shaped. The resulting functionalities are not only derived from the individual modules, but also from their interaction in an environment of parallel information. New 'smart products'", he continues, "are being created, which are capable of tackling completely new tasks. The upshot of all of this is that, in the long run, software-defined products will not only improve existing systems, but will actually provide an opportunity to create novel system capabilities."

Both of these perspectives are reflected in two major projects; the "Software-defined Manufacturing for the Automotive and Supplier Industry" project (SDM4FZI, spokesperson Prof. Alexander Verl, ISW) and the "Software-defined Car" project (SofDCar, spokesperson Prof. Michael Weyrich, IAS), being carried out at the University of Stuttgart under the auspices of BOSCH in collaboration with the Karlsruhe Institute of Technology (KIT) and numerous other partner organizations from science and industry. The German Federal Ministry for Economic Affairs and Climate Action is providing millions of →

→ euros in funding for these projects. Both projects are linked to the novel research area "Software-defined Mobility",which is being pursued at the University of Stuttgart's Innovation Campus Mobility of the Future (ICM), of which both professors are members of the board of directors and to which the two institutes are contributing numerous scientists with funding from the state of Baden-Württemberg.

SDM4FZI: PERMANENTLY FLEXIBLE PRODUCTION

Researchers in the SDM4FZI project hope to develop production engineering solutions that will enable small and medium-sized enterprises to adapt quickly, flexibly, and efficiently to demand fluctuations, supply bottlenecks, and the demand for bespoke products. Other University of Stuttgart partners include the ISW (which is heading up the consortium), the IAS, and the Institutes of Industrial Manufacturing and Management (IFF) and Software Engineering (ISTE).

The inspiration for the SDM4FZI project arose from discussions between the ISW and BOSCH on how to make factories less rigid in the future. "We at the Institute and the partner companies have been working on the concept of flexibility for a long time, and the software-defined manufacturing method was developed collaboratively by ISW and BOSCH," says Alexander Verl. The core idea is that contemporary information and communication technologies are being introduced into operational technology (OT), i.e., the systems and processes used to control and monitor industrial plants and processes. Our goal is to design a factory that is primarily self-organizing and adapts automatically. Yet so far, only a few companies in the supplier sector in particular have taken full advantage of the opportunities offered by digital technology. "With this project," says Verl, "we now want to create a framework that will help these companies move forward in terms of exploiting the benefits of virtualization, standardization, digital twins, and data models."

As project coordinator Michael Neubauer explains, the key lies in radically decoupling software and hardware: "Think of it like a smartphone, where you first buy the hardware with its operating system," he explains: "Applications can be installed as needed, turning the phone into anything from an MP3 player, to a calculator, or a Gameboy. Our aim is to develop a similar approach for production technology." To date, however, this has been hampered by the fact that production systems, as well as those used across the various stages of the supply chain, are based on totally different system architectures, which have been developed organically for specific applications and neither speak the same language nor are able to exchange data with each other.

END-TO-END INFORMATION THROUGHOUT THE SUPPLY CHAIN

This is why one of the work packages in SDM4FZI deals with the development of reference models that will serve as a communication basis for decentralized but networked systems. Rebekka Neumann, a research associate at the ISW, uses an example to explain the requirement: "Imagine a machine component needs to be replaced," she says, "you would need information about both the machine and the component, for example about how they interface with each other, current and voltage ratings, or, in the case of a sensor, its output signal. All of this information should be available in a suitable format to avoid having to compile it manually and our goal is to create just such an end-to-end information chain."

To achieve this and create a virtual representation of the production system, data models are used to describe the three central elements of production, i.e., the products, manufacturing processes, and resources (e.g., machinery), whereby the reference model forms a meta-level that describes the relation between the various data models. Once these relationships are understood, it becomes possible to dispense with rigid production processes and to modify specific process steps or bring in other pieces of equipment during the production sequence in order to optimize the process as a whole.

The Digital Twins mentioned above are a key element in the practical implementation of software-defined manufacturing (see info box). "These," as Verl explains, "describe the production process by means of data, information, and behavioral models created over the entire machine or product life cycle. Coupling a piece of equipment with →

Photo: Bosch

A digital twin of a welding robot

DIGITAL TWIN

A digital twin is a virtual replica of a real-world object, which makes a comprehensive exchange of data possible and enables complex products and processes to be modeled, tested, and optimized in the digital sphere before being manufactured and later operated in the real world. Digital twins comprise one or more models of the object or process they represent, and may also include simulations, algorithms, and services that describe, influence, or provide services in relation to the properties or behavior of the modeled object or process. Digital twins are an indispensable part of so-called Industry 4.0 developments and the Internet of Things and could become part of our everyday lives in the future, not only in the manufacturing and automotive sectors, but also in such areas as medicine and "smart" living.

Prof. Alexander Verl

"Using a digital twin to start up a plant allows for a more efficient process, less downtime, and improved product quality."

Research Associate, Rebekka Neumann, is interested in "Software and Engineering approaches".

Prof. Verl and his team are working in the SDM4FZI project on how companies might be able to operate in a more flexible and efficient manner by adopting novel approaches to production technology.

Institute of Industrial Automation and Software Engineering wants to take vehicle networking to a new level in the SofDCar project.

Using the laptop to revolutionize the car industry: among other things, a new software architecture is expected to provide the basis for autonomous vehicles in the future.

New directions in car production through teamwork: together with Prof. Weyrich and his team, Golsa Ghasemi of Institute of Industrial Automation and Software Engineering

→ the digital twin allows for a more efficient process, less downtime, and better product quality." The SDM4FZI partners want to show how the interaction between the virtual and real worlds actually works in the "Stuttgart Machine Factory", a software-defined factory in the ISW's machine hall, in which the production technology of a manufacturing plant is simulated using real industrial machinery and equipment as well as logistics systems. The factory uses a variety of manufacturing processes to autonomously produce complex products with a whole range of distinct features. "Using this approach," says Michael Neubauer, "it is possible to model the products in the virtual world first in order to plan the interaction between different resources and, if necessary, to revert to a plan B or C. One can also predict manufacturing quality, production costs, and lead times in this way and adjust the strategy before a plan is implemented in the real world with the associated real costs."

SOFDCAR: VEHICLES AS NODES IN AN EXTENDED NETWORK

Under the leadership of Prof. Michael Weyrich of the IAS, eight working groups from three departments at the University of Stuttgart as well as the Research Institute for Automotive Engineering and Powertrain Systems Stuttgart are collaborating in the Software-defined Car project (SofDCar). As Weyrich explains, while SofDCar also has its sights set on the automotive industry, its focus is different: "The corporate and product scene that we want to network," he says, "is dominated by a handful of major manufacturers and suppliers, who have the power to influence systems in a very significant way. But on the product side, there are currently many millions of vehicles all over the world using the roads under a plethora of technical, legal, and ethical framework conditions."

PROF. MICHAEL WEYRICH

"The novel thing about our approach is that we think of every individual vehicle as a node in a networked vehicle and system topography."

Researchers in the SofDCar project are focusing on electrical, electronic, and software architectures in a completely novel way by putting the software at the forefront of the system, whereby there are two distinct levels involved. The first step is to get control of the over 100 control units and functions commonly found in existing vehicles. "However," says Weyrich, "the bigger picture is different. The novel thing about our approach is that we think of every individual vehicle as a node in a networked vehicle and system topography." And, as project coordinator Matthias Weiss explains: "Another of our goals is to enable the digital sustainability of existing and future generations of vehicles, as well as using data effectively, in addition to which we are also looking at innovative use cases throughout a vehicle's lifecycle."

All elements of networked vehicles continuously transmit and receive information, whether within the vehicle itself, between different vehicles, or between the vehicle and the traffic infrastructure, such as stoplights or parking facilities, so the big question is how to implement these connections via a software architecture, which is where SofDCar's digital twin comes into play, which can map the information pool of an entire fleet and, more importantly, manage the so-called "data loop", i.e., the connection between the circulating vehicles and the manufacturers. This feedback loop is currently static but the respective measurements will be dynamically adaptable and continuous across the entire vehicle fleet in the future. As Weiss points out: "This data can be used for development purposes throughout the entire life cycle of a given vehicle with a view to permanently honing the algorithms and, in turn, the vehicles themselves."

This data exchange will also lead to completely new vehicle functions: a vehicle could, for example, receive warnings about traffic bottlenecks in the immediate vicinity from another vehicle that is currently on the road in question – in real time rather than as a time-delayed radio announcement. This kind of micro function already exists, but the big vision is fully autonomous driving. Weyrich is convinced that "it will take a while to achieve this, but we're putting the foundations in place.". →

Risk assessment specialist Junior Professor Morozov attempts to identify software errors in order toanalyze and mitigate risks.

DR. ANDREY MOROZOV

"Our task, is to check the data to verify that everything is okay."

→ Yet this presents significant challenges, due to the sheer volume of elements that need to be interconnected. The security issues associated with the "software-defined" concept are even more serious, and this applies to both projects. "The problems begin with simple data theft, i.e., the risk that software could be stolen or copied and reprogrammed to the detriment of the owner," as Alexander Verl explains. The safety issues involved in autonomous driving are even more critical, given that an error in the software could easily cause fatalities. "This," as Weyrich adds, "means that the processes and infrastructure for releasing and distributing the necessary software and data need to be appropriately safeguarded."

FAULT FINDING AS A KEY CHALLENGE

Of course, this means that one first has to identify the bugs, which is something that Dr. Andrey Morozov, a Junior Professor at the IAS, who is also working on both projects, specializes in. His focus in the SofDCar project is on anomaly detection. "Our task," he says, "is to check the data to verify that everything is okay." Not an easy thing to do in complex cyber-physical systems, in which it is difficult to identify the exact reason for the malfunction, which, as Morozov explains, is why troubleshooting is carried out at different levels. For example, faults at the component level manifest themselves in the form of sensor, control system, or network errors. More complex problems can be detected at the vehicle level, which result from component interactions, for example, when the vehicle accelerates but the sensors indicate that its speed is decreasing. Any unusual behavior on the part of the driver could also indicate that something is wrong. And, at vehicle fleet level, the focus is on traffic anomalies. "The hardest thing in this context," as Morozov explains, "is to recognize which indicators are relevant at any given moment within the infinitely vast amount of available data. It is critical to dynamically manage what we are paying attention to depending on the context. If, for example, we are charging an electric car in the garage, we need to focus on the battery controller, but when driving in the city at rush hour, we need to focus more on our surroundings." →

→ Morozov and his team are using artificial intelligence and deep learning to enable the vehicle to autonomously identify the plethora of potential anomalies in the system as a whole. The research team already developed a so-called "KrakenBox" in 2020, which is a device that can be programmed with the aid of a neural network to autonomously detect faults in industrial cyber-physical systems with no human intervention. Morozov emphasizes the fact that neural networks are particularly well suited to deal with these issues because, as he explains: “they are good at remembering the origins of a given signal and predicting its future development. By comparing this forecast with what actually happens, you can then assess whether something might go wrong in the near future."

So, whereas Morozov focuses on risk mitigation in the SofDCar project, his contribution to the SDM4FZI project is all about risk analysis, which has traditionally been a one-off process before a system goes into operation. But, in the case of software-defined manufacturing (SDM), any software update could have a potentially drastic impact on the process and create new risk scenarios: new hazards are continuously emerging, so the risk analysis also needs to be automated in order to be carried out before any software update. Researchers use risk assessment models to describe how likely a disruption is to occur and what damage it may cause. However, as Morozov explains, the problem is that: "The number of potential risk scenarios rises exponentially in any complex system."

LEGAL AND ETHICAL ISSUES

In addition to these technical hurdles, software-defined systems are also subject to tricky legal and ethical issues. For example, as Weyrich explains, in this "delicate information scenario," the built-in sensor systems needed for automated and autonomous driving facilitate the collection of a wide range of data about the vehicle, its occupants, and its surroundings, such as video recordings of what is happening inside and outside the vehicle. Various countries and even continents have very different views of what is desirable, still permitted or prohibited, and in some cases the respective standards are even contradictory. Weyrich is aware that "there is an enormous amount of social tension relating to this field, which still receives little attention,” and resolving these issues goes beyond the project scope. But the IAS director emphasizes: "This is something that we are continuously discussing in relation, for example, to the European Commission's legislative framework, as well as in numerous other initiatives. This involves some difficult questions, but we are wide open to the relevant discussions." →|

Prof. Weyrich (M.) together with other members of the Software-defined Car project

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PREDICTIVE SERVICE

A smart service offering aimed at SMEs: Dr. Daniel Roth

TEXT: Jens Eber

The goal of the bi.smart research project is to develop a data-based product service to support small and medium-sized enterprises in particular. Among other things, this could herald significant advances in machine maintenance.

The traditional business model for small and medium-sized companies usually involves developing a high-quality product designed for a moderate production volume. The engineers and industrial technicians invest all their expertise in the respective product. However, as soon as the customer is able to use it without any problems, the contact is usually broken off – at least until a spare part is needed.

The purpose of smart product service systems is to redefine the relationship between manufacturers and customers and to create added value for both sides through data-based offerings. Yet, Dr. Daniel Roth of the Institute of the University of Stuttgart's Institute for Engineering Design and Industrial Design (IKTD) is convinced that this will require a paradigm shift. Roth and his team are investigating how it might be possible to introduce and implement a smart product service system in small and medium-sized enterprises in their bi.smart research project. The huge demand for this can be seen just by looking at the sponsors and project partners: the German Federal Ministry of Education and Research (BMBF) is providing two million euros in funding for bi.smart, which is being managed by the Karlsruhe Project Management Organization (PTKA). In addition to the → Karlsruhe Service Research Institute (KSRI), the project consortium also includes the Karlsruhe Institute of Technology (KIT) and the Stuttgart-based Fraunhofer IAO, as well as five medium-sized companies from Baden-Württemberg and the technology provider EDI.

Dr. Daniel Roth

"THIS WOULD ASK THE CUSTOMER TO ENTER SMALL BITS OF INFORMATION BEFORE FINALLY PRODUCING A SET OF RECOMMENDATIONS FOR THE COMPANY."

EARLY MACHINE MAINTENANCE ENABLED BY DATA

Precitec, a manufacturer of laser cutter heads based in Gaggenau, is one of bi.smart's project partners and could, for example, monitor the condition of the cutter heads. As Yevgeni Paliyenko, a research fellow at the IKTD, explains, "If the machine were capable of detecting and reporting the current operating status, it would be able to tell an operator that the cutting head was reaching the end of its life."

Whereas in the past, a human would have had to directly check on the machine to see if the laser cutting head was still working correctly and arrange for a replacement if necessary, Paliyenko adds, "we can now offer the same services based on sensor data." This means that machinery maintenance can be carried out before the plant breaks down, in addition to which a company could use the data obtained to further optimize its own product. If, Paliyenko goes on to say, a manufacturer were able to optimize machinery that had previously been too powerful for the customer's actual needs, for example, it could potentially enable the customer to compete successfully with its international competitors in terms of price.

Many major corporations with well-staffed development departments already think of products in terms of customer benefits, yet, small and medium-sized enterprises often face significant challenges when considering additional product services, which is why one of the objectives of bi.smart is to develop a smart launchpad, i.e., as Roth explains, a "digital dialog guide" designed to enable entrepreneurs and their developers to approach potential services relating to their own products without the basic knowledge that this would ordinarily require. "This would ask the customer to enter small bits of information before finally producing a set of recommendations for the company."

LONG-TERM BENEFITS IN INTERNATIONAL COMPETITION

But the bi.smart team is not expecting a smart product service system of this kind to revolutionize the SME world overnight. "If an existing process is working well, then there's no need for change," says Roth. The project manager is nevertheless firmly convinced by the arguments in favor of such services: "If, for example, an imported machine costs a third less, then creating a business model around it that works in harmony with our product would be a great opportunity." Including sensors and digital interfaces for such services in the early stages of development is also crucial. Researchers at the IKTD feel that it is much more difficult to retrofit smart technology systems.

The bi.smart project is scheduled to run until the end of February 2024. The first phase, which has now been completed, primarily involved the IKTD team conducting surveys and compiling their findings. "We can now extrapolate from existing deficiencies to develop specific requirements for a new model," Paliyenko explains. Not many traditional product development models have placed much focus on service development. This is why the bi.smart project is breaking promising new ground by combing potential services into the product development process right from the start. ↠

See here for a video about the bi.smart project.

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Photo: Uli Regenscheit

Faster without rules

TEXT: Jens Eber

Researchers at the Institute of Mechanical Handling and Logistics want to use artificial intelligence to speed up warehouse processes, which could benefit the economy, especially at peak times such as Christmas.

Drivers who arrive at an intersection from different directions are aware of a few clear rules, which (in Germany) are that those who want to continue straight ahead have priority, followed by those who want to turn right, and finally those who want to turn left: easy enough to remember, but in practice it often leads to waiting times when turning left.

Similar congestion can occur in the transportation systems of warehousing complexes in the logistics industry regardless of what they are used for, which costs time and ultimately money. A research team at the University of Stuttgart's Institute of Mechanical Handling and Logistics (IFT) is looking at how warehouse systems could be optimized with the aid of artificial intelligence and the first thing they have dispensed with are strict right-of-way rules.

Automated storage and retrieval systems based on shuttles, i.e., small transport units that move horizontally along the rows of racks, have become very popular in recent years, especially in warehouses containing tens of thousands of storage locations. The shuttles pick up the required goods from the storage bin before moving out of the aisle to a container lift, which transports the goods to the connected conveyor system from where they are moved to the order picker.

USING AI TO AVOID CONGESTION IN LOGISTICS WAREHOUSES

During peak times, such as "Black Fridays," Christmas, or even when a new fashion collection is being introduced, the same things that annoy drivers so much can also occur in warehouses: there are so many shuttles on the "main street" of the warehouse that those of them that "want" to turn out of the shelf aisles are forced to wait or take alternative routes, which also keep the employees who put together the various goods for specific orders waiting.

"That," as Prof. Robert Schulz of the IFT explains, "is why it makes sense to put some thought into how to improve throughput in shuttle systems.” In one promising project, an artificial intelligence algorithm is being honed on a simulation model that uses thousands of training runs to enable it to learn how to increase throughput in the warehouse system. "What we're hoping for," says Schulz, "is an increase of three to five percent, which will make quite a difference at peak times.”

Another researcher, Ruben Noortwyck, also of the IFT, is interested in the planning and simulation of logistical systems with a particular focus on optimizing shuttle systems using "deep reinforcement learning", which involves the use of a software agent that performs the typical work processes of the shuttles in a simulated environment, whereby the better it manages to optimize the flow, the more points it scores whereas points are deducted whenever its efforts result in a loss of time. In this way,the AI program, → which is programmed to gain as many points as possible, gradually converges on the optimum course. It takes an enormous number of training runs until the algorithm has thoroughly mastered the system, internalized it, and optimized it to ensure a smooth flow of materials. "The more training cycles we put it through, the more stable the results," Noortwyck explains. While the result may seem chaotic, this is simply the nature of the matter, as the optimal shuttle flow will not necessarily follow the same rules as a logically thinking person would program into a rigid control system.

THOUSANDS OF TRAINING SESSIONS ON SIMULATION MODELS

Not only does the IFT team want to prove that an AI algorithm is capable of understanding and learning the complex operations within an enormous warehouse system, but also that they can provide economic benefits for the developers and operators of such facilities. "The great thing about this approach is that it doesn't require any physical remodeling of the system," says Noortwyck. The AI agent trains in a software simulation and gradually creates a neural network, which can later be integrated into the warehouse control system. The resulting neural network is not even trialled in real systems until it has completed its training in the simulation model.

One of the benefits of working with simulation models, according to Prof. Schulz, is that: "the simulation is not done in real time, but at a much faster pace, which means we complete a huge number of training sets." However, there still seems to be a great deal of reluctance in the logistics industry, which Schulz can understand as "no one can explain exactly why the algorithm opts for a particular course of action." But, he adds, acceptance is likely to grow soon, as new warehouse concepts are often based on the use of shuttles. The Institute Director is convinced that "this approach will be of interest wherever flexible and self-sufficient conveyor systems, such as the shuttle system, converge." ⇥

Prof. Robert Schulz

"The simulation is not done in real time, but at a much faster pace."

RUBEN NOORTWYCK

"The great thing about this approach is that it doesn't require any physical remodeling of the system."

Prof. Robert Schulz and IFT employee Noortwyck analyzing warehouse processes

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Photos: Gebhardt Fördertechnik GmbH,University of Stuttgart/IFT

Sensitive system: researchers at the University of Stuttgart want to improve shuttle warehouse processes.

Positioning in factories

TEXT: Miriam Hoffmeyer

A promising new process has been developed by a research team at the University of Stuttgart's Institute of Telecommunications, to make it possible to determine positions in buildings accurately and inexpensively without the need for GPS.

Among its other advantages, ARENA2036 at the Vaihingen campus offers ideal conditions for " channel charting" research.

Whereas GPS is excellent for reliably determining outdoor positions, things are not so good indoors, where it is often not possible to receive GPS signals. As was always the case, if you can't find your way around a large hospital, trade fair building, or DIY store, you'll still have to ask people to point you in the right direction. Specially designed technical systems are used in industrial production halls to locate specific positions: car manufacturers, for example, have to document exactly when a specific mobile robot has worked on a vehicle for safety reasons. What all the different processes have in common is that the necessary equipment has to be installed as an accessory. As Prof. Stephan ten Brink, head of the University of Stuttgart's Institute of Telecommunications (INÜ), explains, "Conventional indoor positioning systems are extremely complex and costly to install not to mention being fault-prone and not very accurate." The main reason for this is that internal walls and other objects reflect electromagnetic waves, which makes locational positioning difficult, especially in industrial environments.

PRECISE POSITIONAL LOCATION WITHOUT GPS

Prof. ten Brink is collaborating with doctoral students Florian Euchner and Phillip Stephan to develop "channel charting," a novel method that draws upon communications technology and computer science, their goal being not only to be able to reliably and accurately determine positions, but also to do so in an extremely cost-effective manner without the use of GPS or having to install any extra equipment. "We obtain all of our data from the normal operation of existing cellular and WI-FI networks," ten Brink explains. This data is used to create a virtual map of a wireless channel with the aid of neural networks after which the positions of mobile users can be determined in the following step. Based on the movements of a wireless channel user on the virtual map, his or her probable next position can be calculated in the real world.

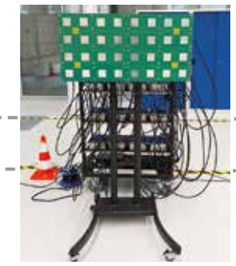
The researchers are primarily conducting experiments in Arena2036, the "research factory" at the Vaihingen campus. As well as researchers from the University of → Stuttgart, various companies and research institutions are using the large hall to conduct research into a wide range of mobile applications. In one corner area, for example, a robot built by Florian Euchner, a doctoral student at INÜ, is making its rounds during the trials: "The Platform was part of a discarded soccer robot that we found on the scrap heap," Euchner recalls. He had to tie the transmitting antenna in the middle with cords to prevent it from wobbling. The robot now sends continuous radio signals to 32 patch receiver antennas via a local 6G research network.

Not only do the patch antennas pick up the direct wireless signals from the robot and other transmitters inside the hall, but they also pick up the phase shifts caused by the many signals that are reflected back from a wall-height metal scaffolding and the many portable walls within the hall, among other things. "Each antenna receives a different reflection profile," Euchner explains: "and, the totality of reflectance profiles received at any given time form one data point." This means that enormous amounts of data can be obtained within a short period of time. The researchers then use neural networks to analyze groups of three data points (triplets) for similarities and differences. "Data points with similar characteristics," as Prof. ten Brink explains, "are highly likely to correspond to points that are spatially close to one another." These "proximity associations" between data points are displayed on the channel charts in color and the resulting graphics correspond amazingly accurately to the areas that the transmitter robot traveled through.

Prof. Stephan ten Brink

"The system still delivers good predictions even as the environment changes."

A prototype of a base station for a novel positioning system: 32 patch antennas receive signals that are then used for "channel charting".



Tireless data provider: a modified robot makes its rounds through the research area, transmitting wireless data along the way.

A RESEARCH TEAM AT THE UNIVERSITY OF STUTTGART IS WORKING ON A UNIQUE PROCESS

The researchers are using a so-called "strong" artificial intelligence algorithm for their studies, which only stores patterns that it recognizes as relevant, rather than indiscriminately storing all of the data it receives, which, as Stephan Brink explains, not only saves storage space, but also results in a more robust system. "The system still delivers good predictions even as the environment changes, which is a constant feature in the real world of industrial production and, of course, here at Arena2036."

To date, very few international researchers have been involved in channel charting. From a technical perspective, the process only became possible with the advent of the 5G mobile communications standard and the associated antenna systems, which make it possible to receive a huge volume of signals. The research team has developed a decentralized and direct storage method for the wireless signals at the receiving antennas to cope with the large amounts of data and use an additional central transmitter to cope with the necessary synchronization. The team is currently refining this unique channel charting process. ↠

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Photos: ARENA2036/Corinna Spitzbarth, INÜ/Florian Euchner

AI FOR EVERYBODY

TEXT: Daniel Völpel

Artificial intelligence and software engineering will probably be among the most important technologies of the future. The Artificial Intelligence Software Academy (AISA) wants to use an interdisciplinary approach to boost these key competencies at the University of Stuttgart both in research and education.

Nadine Koch's doctoral research is focused on how to teach AI literacy.

Artificial intelligence (AI) is a tool that is used in numerous fields such as research, commercial enterprises, and everyday life yet the digital revolution is happening faster than the education and training professions can keep pace with and many teaching professionals have no clue about AI. AI technologies are not part of the curriculum in most fields of study. An interdisciplinary team led by Prof. Steffen Becker, Prof. Felix Fritzen, Prof. Steffen Staab, Prof. Stefan Wagner, and Jun.-Prof. Maria Wirzberger have established the Artificial Intelligence Software Academy (AISA) at the University of Stuttgart to address this issue.

"What we're aiming to do," explains Wirzberger, head of the Teaching and Learning with Intelligent Systems Department and spokesperson for the Interchange Forum for Reflecting on Intelligent Systems, "is to address a gap that hasn't previously been bridged by providing bespoke AI expertise to people with no expertise in the field." Wirzberger heads up the Academy's training department, which provides students with the opportunity to acquire additional qualifications or certificates in addition to their main degree program, whereby the focus is always on AI skills and software engineering (SE), which, in this case means designing and creating the requisite AI programs. The students then link this to applications in their field of expertise, explains Wirzberger.

FUNDING FOR THE AISA FROM THE BADEN-WÜRTTEMBERG MINISTRY OF SCIENCE

The second pillar of the academy, which is coordinated by Prof. Steffen Staab, Head of the Analytic Computing Department at the Institute for Parallel and Distributed Systems (IPVS), is research. Prof. Stefan Wagner, Head of the Department of Empirical Software Engineering at the Institute of Software Engineering (ISTE), is responsible for the overall coordination of the AISA.

The Baden-Württemberg Ministry of Science, Research and the Arts has been funding the AISA since August 2021 and for an initial period through to the end of 2023 with 2.75 million euros. Among other things, the team are using the funding to create their own computer clusters and finance eleven doctoral studentships, whereby each doctoral researcher is supervised by several experts from different disciplines. As Wirzberger explains: "It is precisely through these special combinations that we are able to research interface topics", i.e. the connection between AI and SE as well as their technical application.

Marijana Palalić's doctoral thesis, "Artificial Intelligence for Hybrid Manufacturing of the Future," is focusing on one such interface topic. Her work is being supervised →

The AISA is helping Marijana Palalić of the Institute for Machine Tools to complete her doctoral degree studies under the supervision of experts from various disciplines.

Photos: Uli Regenscheit, private

Jun. Prof. Dr. Maria Wirzberger

"What we're aiming to do is to address a gap that hasn't previously been bridged by providing bespoke AI expertise to people with no expertise in the field."

In the course of her doctoral degree studies, Marijana Palalić examines a cube produced using a novel process.

Jun. Prof. Maria Wirzberger wants to use the AISA to introduce AI into a wide range of study programs.

What may look like a train is actually a modern workplace: this machine enables the production of hybrid components.

→ by an entire team consisting of Prof. Hans-Christian Möhring, head of the Institute for Machine Tools (IfW), an expert in additive and subtractive manufacturing technologies; Prof. Steffen Becker, head of the Software Quality and Architecture (SQA) Department, whose expertise is in model-driven software engineering and software architectures, and Jun.-Prof. Andreas Wortmann of the Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW), who researches model-based development in production automation.

DOCTORAL DEGREE STUDIES IN INTERFACE TOPICS

"We are working on laser cladding with powdered metal," Palalić' explains. In this process, the heat source is a high-power laser, which "melts specific areas of the workpiece while simultaneously adding an inert gas mixed with fine metal powder, which also melts and bonds with the surface of the component, a process that is applied layer by layer." This process can be used to combine different materials in a single component or even to repair → certain areas or parts. It also makes it possible to create geometries that it would be impossible to produce using traditional metalworking methods, whereby barely any waste is produced.

Yet, there are some downsides: "It is almost always necessary to rework any component that has been manufactured using additive manufacturing by removing material, specifically through machining processes such as milling, drilling, and grinding," Palalić explains. This hybrid production method places high demands on the process. In order to ensure that the components manufactured for such applications as aerospace or medical technology do what is expected of them, the individual steps in the process chain have to be precisely coordinated.

However, as the researcher explains, there is still a great deal of uncertainty about the mechanical properties of these components due to the fact that the process of applying and removing material is extremely complex. "There is a huge number of correlating parameters and effects that still need to be studied and whose interactions cannot be described in analytical terms. This is why it is appropriate to use machine learning in this case, and not just to obtain information about what happened during a given process, but also to enable us to make predictions about the quality of the component that were previously impossible."

Palalić's ultimate goal is to develop a virtual model, or a kind of digital twin, of both the component and the manufacturing process, with a view to facilitating the optimization and monitoring of the process, e.g. by identifying errors. Her first step is to install sensors in the machine after which she uses SE to create an efficient software program. As Palalić' explains: "the machine learning algorithms need to be fed with processed sensor data." The third thing she has to do is to correctly select, parameterize, and then apply the algorithms for the particular machine learning AI method and then generate a digital model.

AI LITERACY AS A BASIC SKILL

Wirzberger emphasizes the need to qualify students from non-informatics disciplines in the fields of AI and SE and explains that: "If our goal is to properly equip the skilled workforce of the future, we need to incorporate AI into study programs across the board."

Another special feature of the academy, he adds, is that doctoral students such as Palalić co-supervise the AISA seminars and advise students on AI or SE issues. "For example," says Wirzberger, "if a student would like to use an AI-powered algorithm in the context of a master's thesis and has questions about it, we're the ones who can provide assistance and feedback." Increasingly, AI literacy is becoming a basic skill that everyone needs to master. I need to understand what drives these systems; how much trust I can place in them, and at what point would I need to apply particularly critical thought?"

In her doctoral thesis, which Wirzberger and Becker are jointly supervising, Nadine Koch wants to find out how this competence could be taught more effectively. "It's about developing AI didactics for people with no expertise in AI," Wirzberger explains. "How can I systematically and clearly communicate to non-AI professionals how to select a particular algorithm, recognize its advantages and disadvantages, and how it can be used and evaluated? Can I do it by using well-established forms from teaching/learning studies or computer science didactics? How should I adapt them?" Because once we have answers to these questions, even more skilled workers will soon be able to start their professional lives being AI-competent. →|

Marijana Palalić

"(it also enables) us to make predictions about the quality of the component that were previously impossible."

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Photos: Uli Regenscheit, Sven Cichowicz, University of Stuttgart/IfW

On the way to smart IT

Prof. Dr. Christian Becker

“Normally, we're not even aware of the kinds of problems IT systems have to successfully deal with in the background in order to function smoothly.”

TEXT: Michael Vogel

A team at the Institute for Parallel and Distributed Systems (IPVS) is currently researching concepts for how IT systems could be made to collaborate intelligently in given contexts.

Wi-Fi or mobile communications? Managing smartphone connections can be quite tricky.

It all seems quite simple: countless sensors and mini-computers communicate in the Internet of Things to form a networked, intelligent system. All of our digital devices – smartphones, smartwatches, fitness trackers, virtual reality goggles, etc. – will then interact with the Internet of Things to make our daily lives more convenient. One of the terms that has been coined to describe this is “pervasive computing”, the idea being that computing power is ubiquitous and permeates every aspect of our lives. But it takes quite a bit of effort to get all the systems to communicate with each other and exchange precisely the right information at the exactly the right time.

Prof. Christian Becker, head of the Distributed Systems Department at University of Stuttgart’s Institute for Parallel and Distributed Systems (IPVS) is currently researching ways of facilitating the seamless interaction of such heterogeneous systems. "Normally," he explains, "we're not even aware of the kinds of problems IT systems have to successfully deal with in the background in order to function smoothly." Take the smartphone, for example: it automatically establishes a link either to a WI-FI router or to the cellular network, but if you wander around with the device you could easily go out of range of the WI-FI system to which it was connected and then drift back into range a bit later. The question is: would it be more cost-effective for the smartphone to switch back and forth between Wi-Fi and cellular networks, or would it be better to simply stay connected to the cellular network, despite the fact the connection is poorer, albeit more stable?

There is no simple answer to this question. Any such switch drains the smartphone's computing power, and thus its battery life but, at the same time, the wireless connectivity of a smartphone has to be as good as possible. "So it all comes down to user behavior," Becker explains: "It may well make sense to temporarily switch to the poorer network if someone is sitting at their office desk and just wants to get a quick cup of coffee." Regardless, staying connected to the Wi-Fi makes no sense when someone leaves the building. It would be possible to improve the management of wireless connections if such information were available to the devices.

CREATING THE BASIC REQUISITES FOR SYSTEM INTEROPERABILITY

But, rather than trying to find the optimal solutions to such issues, Becker's research is focused on how to come up with a universal description of the technical systems involved in order to be able to answer the aforementioned questions as easily as possible. "We're not creating applications, we're just trying to identify as many components and constraints as possible that would be necessary to develop a universal description of the basic problem."→

→ Of course, the same issues apply to existing technologies. "Although these systems can identify a suitable configuration," Becker explains, "they often do so poorly." For example, cellular phone companies always simply log mobile smartphone users into the strongest 4-G cell, regardless of which route the user is likely to take. Yet, if the user in question is traveling down a highway, it should be obvious which wireless cell they will encounter next. If the mobile communications company were able to anticipate this imminent connection requirement, they would be able to pre-warn the computers in the relevant wireless cell to have the necessary services ready in advance, which could be used as soon as the vehicle in question enters the wireless cell coverage area. At present, this only works properly as long as the relevant services are known and available by default, such as is the case with traditional telephony.

"At first glance, this may seem like a solution to a rather trivial problem," says Becker, "but, for example, anyone taking part in a video conference while driving in a car will already know the value of having a constant connection quality." So-called edge computing involves research into infrastructures that can provide such bespoke services to mobile devices and linking pervasive and cloud computing via the mobile network. "The resulting synergy really is greater than the sum of its parts," according to Becker.

GENERAL APPROACHES TO A WIDE RANGE OF PROBLEMS

These days, problem-solving approaches are still highly specific, which means that developers have to start again from scratch if the application scenario changes, which, as Becker explains, "is inefficient.” This is why he and his team are trying to develop more general approaches " to enable systems to respond to changing requirements in a predictive way, without having to specify the problem in detail ahead of time."⇥

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Photos: IStock, Siegfried Herrmann

Christian Becker

The 54-year-old computer scientist has been Head of the Distributed Systems Department at the University of Stuttgart’s Institute for Parallel and Distributed Systems (IPVS) since April 1, 2022 when he accepted an appointment to a W3 professorship. Born in Hanau, he studied computer science in Karlsruhe and Kaiserslautern and earned his doctorate at the Goethe University in Frankfurt am Main. Prior to accepting his current position at the University of Stuttgart, he was a professor of business information systems at the University of Mannheim.

Using AI to track down software bugs

TEXT: Michael Vogel

Even complex and rare errors in computer programs can be detected with the aid of neural networks, an area of research being spearheaded by team at the University of Stuttgart.

Modern software programs consist of millions of lines of code and faults (bugs) are almost inevitable, which is a rather worrying thought given the increasing importance of information technology. Published data about the number of bugs in a typical piece of software varies. One of the more frequently cited sources, a reference book called Code Complete, cites an industry average for existing commercial software of one to 25 bugs per 1,000 lines of code. "This range has remained relatively constant over the last decades," says Prof. Michael Pradel, Executive Director of the University of Stuttgart's Institute of Software Engineering (ISTE), "because even as software quality is increasing, programs are also becoming more and more complex.

Developers go to great lengths to avoid bugs, or at least to detect them before a program is delivered. "They use everything from development tools that identify bugs as the code is being written, to software testing by professionals and ordinary users," says Pradel. We now have automated tools that help software development teams to avoid errors by analyzing the program code in a strictly logical way. These tools can detect such things as when a particular command that is meant to point to another location in the program code actually leads to a black hole, or when a non-existent sixth element in a list of five elements is accessed by the program code. However, there are only a few hundred experts around the world capable of developing such automatic fault finders.

FUNDING WORTH MILLIONS FROM AN ERC STARTING GRANT

"This," as Pradel explains, "accounts for the rapid development of neural network analysis, or artificial intelligence, as a research field over the past five years." The computer scientist and his team are at the forefront of this development. He received an ERC → Starting Grant from the EU in 2019. Pradel will now have access to 1.5 million euros, spread over five years, for research into neural software analyses.

Neural software analyses enable such things as reverse engineering, i.e., the derivation of the original source code from a fully functional program. They can also be used to insert annotations in existing source code, for example, to facilitate the auditability or maintenance of a piece of software. Pradel's team is active in both of these application areas and is also one of just a handful of research groups outside of major software corporations, such as Google, Meta, and Microsoft, working on what might be referred to as the king of research disciplines in the IT field, i.e., fault analysis.

Prof. Michael Pradel, Executive Director at the University of Stuttgart's Institute of Software Engineering (ISTE).

"The goal of our approach is to find bugs in the code that automated strictly logic-based tools have trouble detecting," he explains. These are the kind of errors that occur, for example, if a variable assumes a value during a calculation that it cannot have by definition, but it goes unnoticed. An example of such a case would be assigning a probability of 101 percent, because probabilities are always between zero and 100 percent by definition, yet this is the kind of thing that could happen if, for example, a program fails to account for rounding errors. "However," the researcher explains, "this type of intermediate value never appears anywhere at the end of the calculation because it is not permanently required, which makes it difficult to find the fault." Other faults that are difficult to detect are those that result in an error message when using a piece of software, but where the message is very unspecific: indeed, the message may even point in the wrong direction due to the complexity of the underlying fault.

FEEDING TRAINING PROGRAMS WITH SPECIFIC FAULTS

Pradel's team modifies existing neural networks to perform a given task and then trains them to be able to detect specific faults. "We use public domain code from open source programs as training data." The neural network learns to read the source code like a language and searches it for suspicious patterns. "A ratio of erroneous to error-free data of one to one is ideal for training our neural networks efficiently," Pradel explains, "which is why we selectively insert bugs into the training data." However, humans find it difficult to conceive of the full range of potential rare faults, "which is why we're also using a second neural network to automate the bug creation process." One network creates the bugs and the other is tasked with finding them.

Prof. Dr. Michael Pradel

"The goal of our approach is to find bugs in the code that automated strictly logic-based tools have trouble detecting."

Pradel's team has already demonstrated that these approaches work and has developed prototypes of various tools required for neural network-based fault analysis. Along the way, the researchers were also able to detect dozens of previously unknown bugs in open source software as a kind of fringe benefit. "Of course," says Pradel, "the respective open-source communities were delighted to have these pointed out to them." ↠

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Photo: Katrin Binner, Shutterstock/Best-Backgrounds

Photos: HLRS, University of Stuttgart/IER

MAXIMUM PERFORMANCE WITH LESS ENERGY

TEXT: Miriam Hoffmeyer

Although powerful data centers are indispensable for the online sphere, they consume an enormous amount of electrical power, which is why several projects currently being conducted at the University of Stuttgart are aiming at improving their energy efficiency.

PROF. PETER RADGEN

"Policy makers and operators are increasingly coming to the realization that data centers need to become more environmentally friendly."

The Hawk supercomputer is the flagship system at the High Performance Computing Center in Stuttgart

The energy demand of data centers is increasing year by year. Estimates by the industry association Bitkom indicate that German data centers consumed more electricity than the city of Berlin in 2020 – 116 billion kilowatt hours and data traffic has increased further since the start of the Covid-19 pandemic due to video conferencing and private streaming. This development is being accelerated by new technologies such as artificial intelligence (AI), autonomous driving, the Internet of Things, and the expansion of the 5-G network. Because an increasing number of companies are foregoing their own server rooms in favor of co-location centers, there is a trend towards large data centers that can consume up to 300 megawatts of power, which has the potential to cause local power supply bottlenecks and generate a lot of waste heat.

"Data centers make an important contribution to digitalization and thus to increasing efficiency in other areas," Prof. Peter Radgen of the University of Stuttgart's Institute of Energy Economics and Rational Energy Use explains, "but that makes them both part of the problem and part of the solution. However, policy makers and operators are increasingly coming to the realization that data centers need to become more environmentally friendly."

Several projects at the University of Stuttgart are currently laying the groundwork for this to happen. Radgen is heading up the Peer DC project, which is funded by the German Environment Agency and was launched in October 2021. The IER's intention is to establish a nationwide energy data center energy efficiency register together with five partners whose initial aim is to create a reliable database. This is because, so far, all figures have only been based on estimates, as Germany's data centers are neither statistically recorded nor is their energy consumption measured or reported by the operators. Germany is →

Dr. Thomas Bönisch

"The key question is how to modify the respective structures to achieve the same result with less energy."

Researchers at the HLRS are also working hard to find ways to make data centers more energy efficient.

→ home to around 52,000 data centers, the largest in Frankfurt am Main and other major cities. "However," as Nicola Schuckert, a research associate at the IER who specializes in geoinformatics, explains, "no one knows exactly how many data centers are located where, or how much power they consume."

Their project began with questions concerning definition and coming up with size classifications: "Not every company with a couple of servers in the basement counts as a data center," she says. It is even harder to distinguish between the share of electricity consumption accounted for by information and transmission technology and how much is used to operate the buildings and other technical infrastructure. The most complex thing to assess is how energy-efficient the computing power is: we currently lack any meaningful and established metrics, or key performance indicators. Peter Radgen explains: "You sometimes have to dig much deeper and develop the appropriate metrics, which presents a challenge."

In addition to the registry, the Peer DC research team is developing a program for assessing energy efficiency, which data center operators will eventually be able to use. "The software queries certain values and finally produces a file that can be directly uploaded to the registry," Schuckert explains. "This will also provide operators with an overview of their consumption levels, which is in their own interest, and co-location tenants will put more thought into energy-efficient computing." The plan is for the evaluation system that the research team is developing to be transferable to the European level as well.

AN ENERGY EFFICIENCY REGISTER TO ESTABLISH THE BASIC GROUNDWORK

The team will be holding in-depth discussions with data center operators to ensure that the new registry is accepted. "We will be designing two front ends to the registry to accommodate the interests of the operators," says Schuckert Zip code areas and energy consumption will be mapped in the publicly accessible section, but not the precise locations of the data centers, whereas state agencies will be able to access all the data. One benefit of the register is that it provides local authorities with a planning basis for using waste →

Michael Resch has been director of the High Performance Computing Center Stuttgart since 2003.

Prof. Michael Resch

"Our hope is that our findings and recommendations will help others in the IT industry to adopt more sustainable operating practices."

→ heat from data centers for district heating, which would also reduce the amount of cooling energy required.

The "ENRICH" project (Energy, Sustainability, Resource Efficiency in IT and Data Centers), which is being run under the auspices of the High Performance Computing Center Stuttgart (HLRS), takes a holistic approach. Since April 2021, multiple working groups have been investigating a broad range of topics related to data center energy efficiency covering everything from the use of new technologies such as AI and the operation of digital infrastructures to supply chain management issues, waste heat recovery, and user behavior. The ENRICH project is building on years of commitment to sustainability at the high-performance computing center, which is certified under the EU Eco-Management and Audit Scheme (EMAS), for which it has already been awarded a Blue Angel. The IER, Dialogik, a private research institute, the University of Ulm, and Hewlett Packard Enterprise (HPE), who built the Hawk supercomputer at HLRS, are also involved. The two-year project was commissioned by the Baden-Württemberg Ministry for the Environment, Climate and Energy Management.

In the past, as Dr. Thomas Bönisch, an expert in high-performance computing at the HLRS explains, the performance of each generation of microprocessors doubled, whereas the energy requirements remained almost the same. "Nowadays, incremental efficiency increases are much smaller." One of the things Bönisch is working in the ENRICH project is the energy efficiency of deep neural networks: "The key question," he explains, "is how to modify the respective structures to achieve the same result with less energy." For example, he continues, certain connections between neurons could be dispensed with, depending on the objective.

ENERGY EFFICIENCY FROM SUPPLY CHAINS TO HARDWARE

Another team at the HLRS, led by Dr. José Gracia, is investigating the influence of energy-saving hardware components and more efficient computer operation methods. "A computer that only runs Microsoft Word gets bored," he says. "We create models to determine which parts of the processor could be shut down when the workload is low without significantly degrading performance."

Another working group at the HLRS is looking into supply chains. "The goal is to achieve a better balance between the key factors that influence the purchase of new hardware, software and other digital office equipment," research assistant Inna Wöckener explains: "This also includes sustainability in addition to meeting technical requirements, complying with procurement guidelines, and being cost-effective." Wöckener is interested in the entire life cycle of a product, such as an energy-saving SSD hard drive, starting with the extraction of the raw materials and ending with its disposal as electronic waste. Like the Peer DC project, the ENRICH project also takes account of the needs of supercomputer system users: participants in two workshops on video streaming and home offices were surveyed with a view to determining how data centers could potentially reduce their energy consumption by, for example, expediting the modernization of home office access networks.

The project will culminate in the creation of a "Digital Atlas" for Baden-Württemberg, which will provide stakeholders from business, politics, administration, and citizens' initiatives with a geographic overview of relevant facts, figures, and forecasts relating to digitalization. This atlas may also make it easier for municipal planners to exploit waste heat from data centers for district heating purposes. Project manager Prof. Michael Resch, director of HLRS, is optimistic that the ENRICH project will result in new ways to reduce energy consumption in data centers: "Our hope is that our findings and recommendations will help others in the IT industry to adopt more sustainable operating practices." ↠

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Photos: HLRS, Boris Lehner

CONNECTIVITY IN FIGURES

There are many interpretations of the term "connectivity": networking, being connected, connectivity compatibility, but also "being dependent on some external thing". The tangible effects of connectivity go far beyond technological issues thanks to the convergence of digital infrastructures and services. The process of digitalization is revolutionizing communication tools, creating more agile production processes, enabling power grids to adapt to the requirements of the energy transition, and much more.
The University of Stuttgart's vision of "intelligent systems for a sustainable society" is also based on connectivity as a key element. The principle of networked faculties, collaboration between complementary disciplines through the integration of engineering, the natural sciences, the humanities, and the social sciences, is anchored in our mission statement under the term the Stuttgarter Weg (Stuttgart Way).

12 megatrends have been identified by the Frankfurter Zukunftsinstitut (Frankfurt Future Institute), which was founded by trend researcher Matthias Horx, which are considered to be the great drivers of change. In addition to connectivity, these include such things as health, gender shift, mobility, and new work.

4 target areas for the digital transformation in Europe up to 2030 have been defined by the European Commission to bring about the digital transformation in Europe by 2030 including the development of computer skills, the digital transformation of businesses, the digitalization of public services, and secure and sustainable computer-based infrastructures.

500,000,000,000

devices will be networked by 2030 according to a study by the German Federal Ministry for Economic Affairs and Climate Action and their number is increasing constantly.

7 strategic goals are included in the University of Stuttgart's mission statement including networking different disciplines.

2036

Connectivity is a lived experience at the University of Stuttgart's ARENA2036 research campus, both in terms of the research subjects they study and through their close collaboration with a wide range of industrial partners and institutes. The ongoing exchange of ideas and close proximity give rise to completely novel ideas that can quickly be implemented and tested on site.

47 partners are networking in the Mobility of the Future Innovation Campus (ICM), with support from the University of Stuttgart and the Karlsruhe Institute of Technology (KIT). Researchers in two strategic research fields, Advanced Manufacturing and Emission-free Mobility, are looking into such issues as product development, production, and products for sustainable mobility.

Game changer in the energy crisis?

TEXT: Claudia Zöller-Fuß

Both the research community and society at large are concerned with alternative green energy sources and the concomitant independence from fossil fuels and external suppliers. Researchers in the H_2Mare project, who are investigating the production of green hydrogen on the high seas, could make a significant contribution to the desired energy transition. Two University of Stuttgart Institutes are participating in the project.

A groundbreaking undertaking: the objective of the H_2Mare project is to produce green hydrogen on the open ocean as well as so-called power-to-X by-products.

Illustrations/Photos: project sponsor Jülich on behalf of the BMBF, private

Two marine technologies considered to be very promising for the future are the production of green hydrogen and its direct processing into so-called Power-to-X (PtX) products. The H_2Mare project is one of the three flagship hydrogen projects being run by the German Federal Ministry of Education and Research to implement the National Hydrogen Strategy. Researchers in the PtX-Wind project are investigating new production processes for hydrogen and its derivative products. The purpose of this development initiative is to provide a vital boost to Germany's entry into the hydrogen economy and represents a beacon of hope in the struggle against climate change.

The University of Stuttgart Institutes are working on one of the central challenges of this research project, which is about finding the best possible way for all the system modules and stakeholders on the planned research platform to work together. One of the tools the researchers are using in their search for answers to these questions is a so-called digital twin, the purpose of which is to provide a detailed picture of offshore operations.

Specifically, researchers at the University of Stuttgart's Institute of Energy Economics and Rational Energy Use (IER) and the Institute of Industrial Automation and Software Engineering (IAS) are collaborating on an application that will ensure that the planned offshore platforms operate at optimal efficiency. This is why researchers at the IAS are collaborating with their project partners to develop the digital twin, which will model all plant modules used offshore throughout their entire lifecycles.

A DIGITAL TWIN ANALYZING SYSTEM MODULES

The research focuses on the various containers used by the project partners from science and industry to house the plant modules for the planned offshore platform, which include everything from the seawater desalination plant and the electrolyzer to the PtX product synthesis systems. The purpose of the digital twin is to perform so-called "hardware in the loop" (HiL) tests on important system modules both before and during real offshore operations. Examples of the tests include different platform configurations and the interaction between dynamic operational behavior and the volatile energy supply from the wind farm.

The first of the challenges involved in creating a simulation using the digital twin is the data acquisition process: "One of the first things we often find," Nikola Mößner explains, "is that we request certain parameters from the project partners, but they are not yet available, which means that we sometimes have to use default parameters that →

PASCAL HÄBIG

"The ultimate project objective is to prove the basic feasibility of this novel production concept."

Offshore wind farms play a central role in the energy transition.

→ can later be replaced by research results." But even exchanging data can sometimes be difficult: "Some of the data and also the models in which it is used are subject to special data protection regulations," says Daniel Dittler, who works on digital twins at the IAS. The researchers have to develop special concepts to be able to use the information while protecting it at the same time; because no simulation experiments can be carried out in the digital twin without this data exchange.

"The exciting part," as Dittler explains, "is that whereas the whole purpose of the digital twin is to represent reality, we don't yet know what that reality will look like." Many of the things that the research offshore platform will have to withstand are known from offshore wind farms and the oil and gas industry, but developing the system configuration will involve stepping into terra incognita. Consequently, the digital twin has to be able to adapt to any changes that occur in the facility during the research project. "The models themselves must be adaptable, just like the digital twin, in order to develop as things unfold so that new elements could be added later, just like a construction kit," →

DANIEL DITTLER

"The exciting part is that whereas the whole purpose of the digital twin is to represent reality, we don't yet know what that reality will look like."

Nikola Mößner

"The models themselves must be adaptable, just like the digital twin, in order to develop as things unfold."

→ Mößner explains. To ensure that this is possible, the processes have to be described as realistically as possible under changing conditions.

LAYING THE FOUNDATION FOR LARGE OFFSHORE PLATFORMS

The objective of the PtX-Wind research project is to create a platform that will draw electrical power directly from an offshore wind farm to produce synthetically generated material energy carriers such as hydrogen in addition to easily transportable so-called PtX downstream byproducts. Carbon dioxide and nitrogen will be needed to produce energy carriers, such as methane, hydrocarbons, green methanol, and green ammonia and the plan is to extract both from the atmosphere and seawater.

"The ultimate project objective is to prove the basic feasibility of this novel production concept," as Pascal Häbig of the IER explains. "This will give us the basic wherewithal to create off-grid and large-scale offshore platforms in the future." Häbig is convinced that the H_2Mare pilot project will contribute towards climate protection while simultaneously reducing dependency on energy exporting countries.

POTENTIAL BEACON OF HOPE FOR A SUSTAINABLE ENERGY SYSTEM

The two Institute Directors, Prof. Michael Weyrich and Prof. Kai Hufendiek, are convinced that it is justified to place our hopes in green hydrogen and its green PtX by-products as a future energy source for important tasks in a sustainable global energy system. Germany will also benefit greatly from the transfer of knowledge and technology through the three pilot hydrogen projects, which involve over 240 project partners from the scientific and industrial communities, not least through the boost they will give to the country as a business location. If the research endeavors being carried out in the H_2Mare project prove successful, it could pave the way for the global scalability of such offshore wind farm island systems and thus for the off-grid exploitation of suitable potential resources marking an important milestone on the road towards the desired energy transition. ↠

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Photos: IStock/CharlieChesvick, private

ONLY STABLE IF FLEXIBLE

Photos: AdobeStock, Fraunhofer IPA/Rainer Bez

While solar energy is expected to supply much of our electricity in the future, there are huge variations in production volumes.

Dennis Bauer of the Institute for Energy Efficiency in Production is head of the "SynErgie" project coordination office.

TEXT: Daniel Völpel

How could the industrial sector adjust its electricity demand to the supply? The Copernicus project "SynErgie" is focused entirely on this central question. The project is being coordinated by the University of Stuttgart's Institute for Energy Efficiency in Production (EEP).

Germany in transition: the bulk of the electricity demand will be met by photovoltaic and wind power plants rather than nuclear, gas-fired and coal-fired power plants. Our power supply is expected to be largely based on renewable energies by the end of this decade with Germany achieving climate-neutrality by 2045. Right now, in 2022, Germans are experiencing the need for a rapid transition due to the war in Ukraine and the associated energy crisis.

The fact that wind and solar power production facilities are not capable of delivering a constant supply of electricity poses a fundamental challenge for the transition: their output varies depending on the time of day and the weather. Yet, a basic requirement for a stable grid is a balance between supply and demand. Just how this could succeed and how the industry might be able to compensate for these fluctuations is currently being worked on by more than 90 partners from science, industry, and society in the Copernicus project "SynErgie".

Supplying Germany with electricity from renewable energy sources will result in a fundamental change for large-scale consumers, for example in the industrial sector: for example, foundries, metal, paper or glass manufacturers have so far been rewarded with grid fee reductions in return for purchasing consistently high quantities. In future, as Dennis Bauer of the University of Stuttgart's Institute for Energy Efficiency in Production (EEP), who heads the "SynErgie" coordination office, explains, they will help to keep the power grid stable by consuming sometimes more and sometimes less wind and solar power." The research project is one of four Copernicus projects that together form one of the largest German energy transition initiatives. The Federal Ministry of Education and Research has been providing "SynErgie" with funding of around ten million euros per year since 2016. Head of the EEP, Prof. Alexander Sauer, is the spokesperson for the overall project which covers six different research areas. →

→ One approach to buffering the fluctuations in the amount of electricity would involve changing industrial manufacturing processes. The Essen-based aluminum producer Trimet provided an example of this: one of their production lines used to need a constant nominal output of 90 megawatts (MW), but the company now has the ability to vary the load and can draw up to 22.5 MW of additional power from the national grid, or else reduce its load by this amount, depending on whether the sun is shining or the wind is blowing.

AUTOMATED PLATFORM FOR FLEXIBLE ELECTRICITY TRADING

Yet this restructuring would be of no use were electricity producers and consumers to fail to exchange information regarding demand and supply. A platform to synchronize supply and demand is therefore a central part of "SynErgie" and the EEP is collaborating on its development with the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA). The Energy Synchronization Platform (ESP) will consist of a business platform and a market platform that will receive and analyze data from both businesses and the electricity market. The "SynErgie" partners demonstrated that the model works in the Augsburg model region in early 2022, when producers and grid operators exchanged data on the ESP for the first time.

As Bauer explains, a reference IT architecture has been designed and completed since the project was launched in 2016, which comprises a system of functions and interfaces that can be integrated into different software programs. "Not all businesses will use the same platform for the energy flexible control of production processes," the researcher explains, which is why the team wants as many software and platform providers as possible to program in the necessary functions in order to map the ESP. The aim is not just to help energy-hungry corporations optimize their energy consumption, but also small and medium-sized enterprises from a wide range of industry sectors. "We have a clear mandate for the third phase of the project, which is to put even more emphasis on targeting industry sector stakeholders and getting them involved in the implementation," says Bauer. The initial focus this year is submitting an application for the funding period until 2026.

By the time the project is completed, the expectation is that the "SynErgie" team will have created all the technical prerequisites and derived recommendations for action on the market side with a view to synchronizing the energy requirements of the German →

Aluminum production is also very energy intensive: to use it flexibly, the Essen-based company Trimet is also participating in the SynErgie project.

Important contribution to the energy transition: an air separation plant from the Linde company exploits n a novel concept to produce energy in a flexible manner.

Dennis Bauer

"Based on some very rough calculations, this means that we'll have to quadruple the installed capacity of renewables by 2035. The concomitant volatility issue will also increase dramatically as this happens."

→ industrial sector with the volatile energy supply. According to calculations by the "SynErgie" consortium, were the system to be implemented nationwide, the industrial sector could absorb an additional 45 terawatt-hours (TWh) of load per year, and reduce its load by 48 TWh . To put this into perspective, Germany's annual electrical power output is around 500 TWh, of which 44 percent is consumed by the industrial sector.

NEW CHALLENGES DUE TO THE WAR IN UKRAINE

The "SynErgie" project and its partners have been impacted by Russia's attack on Ukraine. For example, one project partner had previously converted its magnesium casting furnaces from electrical operation to additional gas firing, meaning that it could switch to gas in the event of a power shortage. "Just six months ago," says Bauer, "no one would have thought that gas would ever become so scarce and expensive." Now the companies will have to upgrade their burners again, for example, to enable them to operate with biogas or hydrogen in the future. Due to the fact that gas is used in electrical power generation in particular then when there is a mismatch between supply and demand, it is even more important to utilize flexibility potentials in industry, as the energy data analysis emphasizes. "It would take years and vast investments to build battery storage facilities." But Germany does not have the time for this. In addition to industrial processes, he adds, heat generation and transportation are also becoming increasingly electrified; eventually, says Bauer, this will roughly double our current electricity demand. "Based on some very rough calculations, this means that we'll have to quadruple the installed capacity of renewables by 2035. The concomitant volatility issue will also increase dramatically as this happens."

From a technical perspective, the system could already cope with this. However, Bauer also sees an inherent difficulty in the current legal requirements: "For energy-intensive industry, the problem is grid charges." With flexible power purchases, companies would lose their rebate for their constant consumption, even though they help stabilize the power grid. As Bauer continues, the current strict separation between the market and the grid would also have to be abandoned, and it would have to become possible to differentiate electricity prices on a regional basis. The "SynErgie"partners are campaigning for these changes in collaboration with certain politicians and are drawing up recommendations for action. →|

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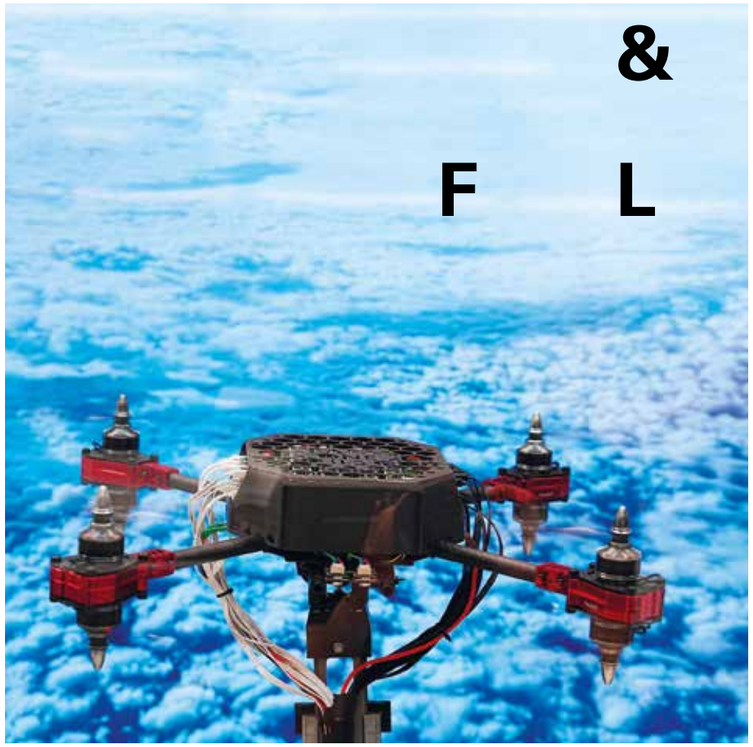
Photos: SynErgie/Linde plc, SynErgie/Trimet Aluminium SE

P L U G & F L Y



Tools for demonstrating auto-configuration: the octocopter

TEXT: Jens Eber

Modern aircraft are crammed with digital components that require complex configuration processes, which is why researchers at the University of Stuttgart want to teach aircraft to configure themselves in the PAFA-ONE project.

Taking an air taxi to the main train station or having urgently needed goods delivered by a high-performance drone? Such options are viewed as the building blocks of future mobility, and, from a purely technical perspective, building small aircraft for individual transport is by no means unfeasible: numerous companies around the world are already working on this.

However, obtaining approval for a new type of aircraft in compliance with the same safety standards as apply to helicopters or passenger aircraft requires extensive testing and approval procedures, which can cost up to tens of millions of euros. Researchers at the University of Stuttgart's Institute of Aircraft Systems (ILS) currently involved in the PAFA-ONE (Plug&Fly Avionics) project are therefore looking into whether these processes could be simplified and partially automated without compromising safety. Just as the software manufacturer Microsoft once promised with its plug and play architecture, digital components in flight systems should also be able to register and configure themselves within the system. The addition of ONE to the project name also indicates that this will be a mammoth task.

"There is currently no function in an aircraft that does not require a microcontroller." says Jun. Prof. Björn Annighöfer of the ILS. This applies to everything from the highly complex flight controls to the cabin lighting and toilet flushing systems. Because the requisite software is usually developed independently of the hardware these days, the plethora of system components have to be coordinated with one another. During this so-called configuration process, the on-board computers are, so to speak, told when → and how to execute a given program, and which sensors to use to do so. "The configuration has proven to be extremely time consuming because of its safety critical nature," Annighöfer explains. Both the hardware and software must be error-free, as must the configuration; only when these components interact is the system able to function perfectly and achieve pre-specified safety states, for example, for flight control, which is defined as a maximum of one critical incident per billion flight hours.

Jun. Prof. Björn Annighöfer

"There is currently no function in an aircraft that does not require a microcontroller."

COMPLETE AUTO-CONFIGURATION REMAINS A DISTANT OBJECTIVE

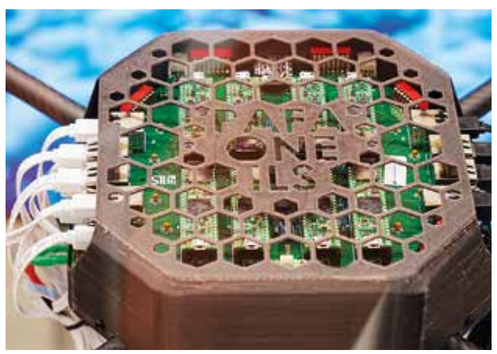
What the researchers in the PAFO-ONE project want to develop is tantamount to a new philosophy for this area of aviation. The objective is for the aircraft's digital systems to perform tasks that are currently carried out by experts in very complex processes: just as a computer boots up when it is switched on and is ready for use after a few moments, a far more complex system such as an aircraft could also configure itself and independently assign tasks to the various digital resources. "That is our long-term goal," Annighöfer confirms. "The system can then demonstrate that it is in a safe state."

However, the research group is initially testing its approaches in less sensitive areas and are using a lab-based demonstrator at the Stuttgart-Vaihingen campus, which represents an auto-configuring cabin system. "It's already working pretty well," says Annighöfer. Cabins, he says, are a particularly interesting application area as they are multi-functional, differ from aircraft to aircraft, and are constantly reconfigured depending on the airline or even the season.

INITIAL APPLICATION IN NON-CRITICAL AREAS ENVISAGED

The PAFA-ONE team has developed several scenarios to explore potential real-world applications, in what Annighöfer refers to as the "most conservative" of these, only certain components are automatically configured during the initial installation of the system. "But that wouldn't deliver the full benefit," the researcher believes. For example, he continues, aircraft have on-board functions, such as door and landing gear controls, which are only needed for short periods, but which nevertheless require background processing power all the time. Were it possible to reconfigure the system dynamically, only those components that were currently required would be active, which as Annighöfer explains: "would reduce the overall size of the avionics system." Clearly, however, auto-configuration would initially only be used in practice in non-critical areas, Annighöfer continues, and could only be used in other areas once it had gained the trust of all those involved.

Although the conventional, multi-million-dollar procedures for transport or passenger aircraft are amortized over time, they represent a disproportionately larger hurdle in the development of new, autonomous mobility concepts. "Such new concepts require highly complex flight control systems," says the aviation expert, "at the same time, they would only start to become economically viable if they did not require pilots. This is where a platform, such as the one we are developing in PAFA-ONE, could help." ⇥



HighTech for PAFA-ONE: the mother board of the Octocopter

Björn Annighöfer (center) and his PAFA-ONE team at the test stand.

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Photos: Jens-Peter Kühn

Bridge made of high-tech materials and flax

TEXT: Bettina Wind

Bridges cross rivers and gorges, and sometimes even differences and conflicts. The EU's "Smart Circular Bridge" project is focusing on the connection between an ancient crop and modern digital technology and its architect is Jun. Prof. Dr. Hanaa Dahy of the University of Stuttgart.

A long familiar plant and construction material of the future: building with flax could be significantly more sustainable than with concrete, metal, or even wood.

Almere in the Netherlands is home to the first high-tech bridge made of flax. A second one will shortly be built in Ulm.

Specialist in bio-based materials: Jun. Prof. Hanaa Dahy of the University of Stuttgart

Photos: Smart Circular Brige, BioMat / Evgenia Spiridonos

While the vast majority of bridges are still built of steel and concrete or even timber, the search for new, more sustainable building materials begun a long time ago. A high-tech bridge made of flax, which was created in the Netherlands as part of the EU's "Smart Circular Bridge" project, is one example of innovative bridge construction. An interdisciplinary consortium consisting of 15 partners under the leadership of Eindhoven University of Technology is responsible for the first of a total of three planned structures to be built during the project. Participants include five universities, seven companies, and three cities as well as architect, Jun. Prof. Hanaa Dahy who heads up the BioMat Department (Biobased Materials and Materials Cycles in Architecture) at the University of Stuttgart's Institute of Building Structures and Structural Design (ITKE) and specializes in the use of bio-based materials in construction. She was also able to bring her expertise to bear on the high-tech bridge built using flax: "The project as a whole provides an important stimulus to show how alternative, biomass-based and annually renewable resources can be used in the construction industry," Dahy explains: Our aim is to use these resources to overcome major challenges such as high CO_2 emissions and high energy consumption in the production of construction materials." →

Jun. Prof. Dr. Hanaa Dahy

"we also need the forests to sequester CO_2 in our struggle against climate change."

→ After all, traditional construction materials, such as concrete and metal, have a negative carbon footprint and are non-renewable. At the same time, the demand for construction materials continues to grow unabated. "Timber is not and should not be used to solve our construction materials shortage. Although it does grow back, it does so comparatively slowly," says Dahy, "and we also need the forests to sequester CO_2 in our struggle against climate change." That is why the researchers directed their attention at raw materials that regenerate rapidly on a seasonal and annual basis, and in particular at one ancient and well-known plant: flax.

FLAX AS A BEACON OF HOPE FOR THE FUTURE OF CONSTRUCTION

Flax, a fibrous plant, combines several properties that are beneficial to the construction industry. When combined with a special bio-resin, it forms a lightweight and highly stable material, similar to fiberglass. It is also more sustainable to build with flax. This ancient cultivated plant is found throughout Europe, which eliminates the need for global transport routes and also grows much faster than, for example, a tree.

However, the researchers are not focusing solely on the bridge construction, but are also asking themselves how the bridge construction materials could be recycled at the end of their service lives, whereby three options are currently being considered: chemical, mechanical, or biological recycling using fungi.

Overall, the flax bridge is seen as a beacon of hope for the future of construction. Dahy says that even during her doctoral degree studies, she wondered why architecture up to that point had only been based on familiar materials such as glass, concrete, and metal. "Why," she asked herself, " isn't anyone researching the potential use of alternative materials?

AI SUPPORTING MATERIALS RESEARCH

The researchers are also relying heavily on modern technology in their search for new materials for use in future construction. "We are very fortunate to find ourselves in the digital era and to have digitalized planning, design and production processes at our disposal, which can help with prefabrication and construction." Digitalization and artificial intelligence are also enabling major advances in materials research. The bridge, for example, is being systematically monitored in real time as part of the project, with almost 100 sensors providing data on the material's behavior on a day-to-day basis to find out how the structure behaves when 200 people walk across it at the same time and what happens at different times of the year, during storms, or under the influence of hail, and snow or how the aging process of the material proceeds in detail.

Some of the project partners have developed a structural health monitoring system, which uses optical fiber sensors installed in the bridge to provide information about deformations. Acceleration sensors detect even the finest vibrations caused, for example, by wind. The data is then analyzed with the help of artificial intelligence to identify patterns in the material's behavior. At the same time, engineers can use this data to refine their computational and material models, which will make it easier to develop the designs for future bridges and numerous other construction projects.

MORE BRIDGES PLANNED

A bridge built of flax will initially be erected in Ulm in the winter of 2022/23 as part of the project, which will be followed by the third and final bridge a year later, which will built in Bergen op Zoom in the Netherlands. Throughout this process, the researchers intend to take account of the data and findings already obtained from previous bridge constructions with a view to developing, a sustainable construction material, step by step. ⇥

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NOTEPAD

MILESTONE IN TERAHERTZ COMMUNICATIONS

Researchers at the University of Stuttgart's Institute for Power Electronics and Electrical Drives (ILEA) have succeeded in presenting the world's first bidirectional terahertz (THz) radio link with an Internet connection as part of the "ThoR" project.

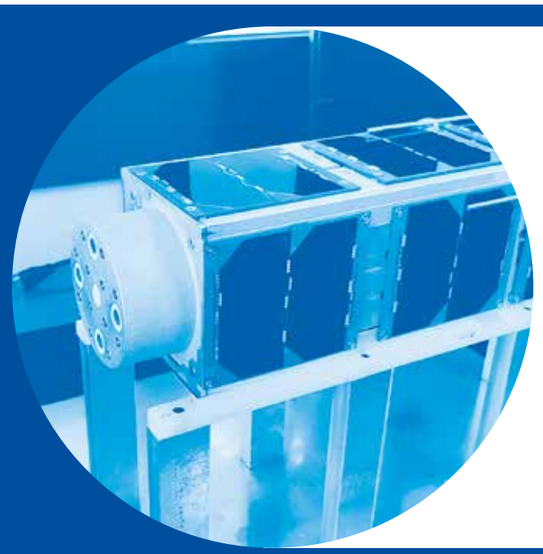
Directional radio links in the terahertz range are an attractive alternative in situations in which high bit rate transmission via fiber optic cables is not possible, for example in dense urban areas, remote locations, or in the event of a disaster and are able to cover distances of up to a kilometer. This creates important "backhaul" connections between mobile cells and mobile network nodes without the need for civil engineering work on roads The high data rates produced by the 5G mobile communications standard and, in the future, the 6G standard, can be transmitted via the radio link.

1 km

Terahertz directional radio links are an attractive alternative in situations in which high bit rate transmission via fiber optic cables is not possible and can cover distances of up to a kilometer.

INNOVATIVE AIR FILTER MEDIA

Not only are the air filters used in buildings important tools in the fight against the spread if Covid-19, they also protect sensitive technical components from being contaminated with everything from ultra-fine particles to viruses and germs. However, these devices consume a lot of energy depending on the filter medium used. Researchers in the NANOFIL project, a collaborative undertaking between the University of Stuttgart and the filter manufacturer MANN+HUMMEL now want to optimize the microstructure of filter media and increase the efficiency of these systems. To achieve this, the researchers rely on simulation science. In particular, there are currently no application-oriented model approaches for the processes involved in the separation of ultra-fine particles on ultra-fine fibers. The main objective of NANOFIL is, therefore, to improve the simulation models that are already established in the virtual development of filter media and to extend them with regard to nanofibers.



PETRUS IN SPACE FOR THE FIRST TIME

The European VEGA-C rocket was launched on its maiden flight from French Guyana on the 13th of July 2022, carrying with it the Italian GreenCube satellite, which is equipped with the PETRUS (Pulsed Electric ThRuster) propulsion system developed by the University of Stuttgart's Institute of Space Systems (IRS). The PETRUS is a relatively simple, robust, and inexpensive electric space propulsion system. From its position on board the satellite, it is providing support for a biology experiment being conducted at the Sapienza University of Rome, whose aim is to cultivate and observe plants under space conditions. Following the experiment, the plan is for the PETRUS to demonstrate its capabilities as a general propulsion system for space applications through various functional tests in orbit. It is particularly well suited for attitude and orbit control as well as for transferring small satellites into orbit.

MICROPLASTICS: SHIPWRECK AS A REAL-WORLD LABORATORY

There are over five billion plastic particles floating on the surface of our oceans – much to the detriment of marine organisms, the delicate underwater ecosystem, and even the climate. Until now, it was only possible to determine how long it takes for the plastic to completely degrade by extrapolating from laboratory data. A shipwreck that took place off the coast of Egypt in 1993 has thrown the researchers a lifeline: the ship was loaded with plastic granules, a portion of which washed up on the beach, while the rest remained trapped within the wreck under 18 m of water.

A team led by Prof. Franz Brümmer of the University of Stuttgart's Institute of Biomaterials and Biomolecular Systems (IBBS) took advantage of this to conduct comparative studies on aging and microplastic degradation for the first time. What they found was that whereas the decomposition of the plastic pellets on the beach has already reached an advanced stage, the plastic pellets on the seabed show hardly any signs of incipient degradation, even over 20 years after the accident.

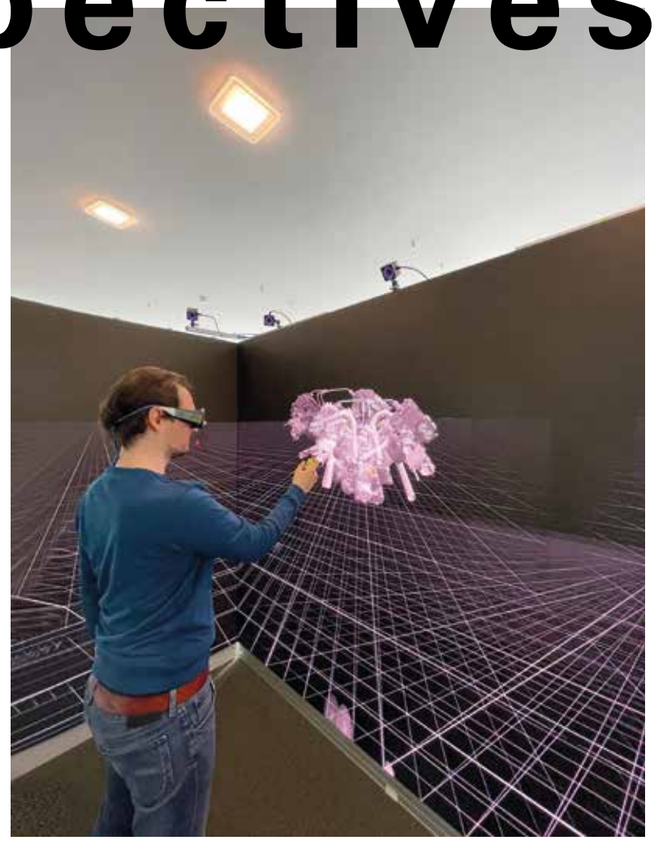
NEXT STEP TOWARDS SYNTHETIC CELLS

Researchers at the University of Stuttgart's 2nd Institute of Physics and the Max Planck Institute for Medical Research came one step closer to creating synthetic cells by successfully introducing functional DNA-based cytoskeletons into cell-sized droplets. Cytoskeletons are essential components of every cell, controlling their shape, internal organization, and other vital functions such as the transportation of molecules between different parts of the cell. Having introduced the cytoskeletons into the synthetic droplets, the researchers were also able to detect various cellular functions including molecular transportation and the assembly and disassembly of DNA-based structures following specific trigger pulses.

Important milestone in medical research on synthetic cells: Researchers have successfully introduced functional DNA-based cytoskeletons into cell-sized droplets

Photos: University of Stuttgart/Dominik Wrana, MANN+HUMMEL, University of Stuttgart/IRS, University of Stuttgart/WiTUS

New perspectives



A personal view: Daniel Diers is able to view 3D objects on the CoLEDWall from his own unique perspective.

TEXT: Bettina Wind

Researchers at the University of Stuttgart's Institute of Human Factors and Technology Management (IAT) are working on a CoLEDWall, which, with the aid of visual display technology,is expected to make the work of engineers easier.

While it looks like a normal LED display wall, such as those used in stadiums, the CoLED-Wall differs in one important respect: its pixels are so close together that viewers can get much closer to it than to conventional LED walls. This enables people to use it in their everyday work in the office. And at 240 hertz, the refresh rate is extremely high. →

The new technology facilitates collaborative working in a virtual world.

→ "We use that feature to output multiple images at the same time, which can then be filtered out using 3-D glasses," explains Daniel Diers, a research associate at the University of Stuttgart's Institute of Human Factors and Technology Management (IAT) and at the Fraunhofer Institute for Industrial Engineering IAO: "and several people can do this at the same time." Diers' area of expertise is program implementation of VR applications. "Our ultimate goal is to use visual display technology to improve the work processes and collaboration between engineers." This is precisely what the CoLEDWall, which already has the word "collaborative" in its name, makes possible.

COLEDWALL VERSUS CAVE

Each viewer sees the virtual 3-D object depicted on the CoLEDWall from their own unique perspective. The fact that several people can view the same object simultaneously is a unique feature and is a major step forward for collaborative working. Several engineers, for example, can simultaneously view a CAD file, which is an image in a two- or three-dimensional format, showing an engine block and consider how best to remove it from a vehicle. Regardless of whether someone ducks down or turns their head, the person in question can still see all the views on the LED wall.

It has long been possible to view virtual 3-D objects in a so-called Cave Automatic Virtual Environment (CAVE), including at the University of Stuttgart. However, the CoLEDWall has certain advantages over this. All participants in the CAVE are shown the object from the same viewpoint, whereas the CoLEDWall enables everyone to have their own unique perspective, and all they need to do so is a pair of lightweight glasses similar to the conventional 3-D glasses familiar from the cinema. This allows everyone in the room to see and communicate with one another, which, as Diers explains "facilitates collaboration", which is not possible with the stereo glasses used in CAVE systems. Its size is another beneficial aspect of the LED wall: at just 2.80 meters wide, 2.25 meters high, and weighing around 400 kilograms, it is significantly lighter and more space-effective than a CAVE, benefits that commercial enterprises have also recognized. "There is definitely interest from the industrial sector and the feedback so far has been excellent." Diers and his colleagues anticipate a growing demand as interest in collaborative working is increasing. ↠

240 Hertz

is the refresh rate of the CoLED wall, which is extremely high compared with other display walls.

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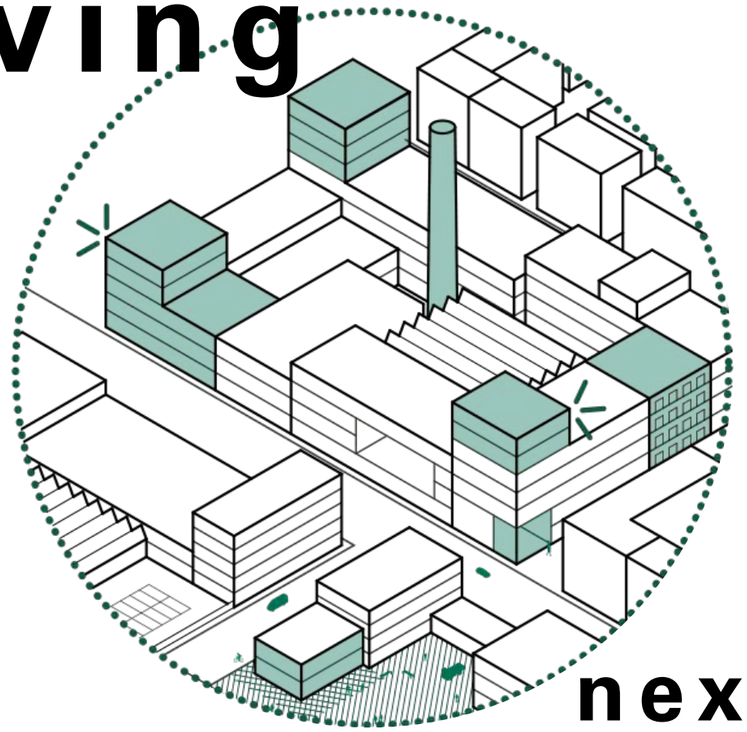
Photo: University of Stuttgart/Daniel Diers, Ludmilla Parsyak, Fraunhofer IAO

Living next to a factory



A factory chimney in the neighborhood: researchers at the University of Stuttgart's Institute of Urban Planning and Design are developing strategies for reconciling the needs of residential and commercial areas.

TEXT: Daniel Völpel

Desolate brownfield sites on the outskirts of cities are still a reality in many places. Dr. Britta Hüttenhain, Academic Director of the University of Stuttgart's Institute of Urban Planning and Design, is exploring ways in which such areas might be upgraded and the needs of urban living and work reconciled.

Urban planner Dr. Britta Hüttenhain is interested in the redesign of commercial zones.

There is a marked separation between living, working, and leisure time in a typical city. Industrial facilities are often located in large business parks outside the city and far removed from residential areas. But this is changing. Urban planners are now thinking about how it may be possible to construct more compact, networked cities in order to conserve resources and create new, sustainable forms of living and working, and the necessary conditions that would enable people to live in the immediate vicinity of commercial enterprises.

As Dr. Hüttenhain has noted in her research, many major corporations have long recognized the disadvantages of purely commercial sites and have been upgrading their sites in recent years. In a bid to attract the best talents, she explains, some companies have installed gastronomic outlets, areas for service providers, and leisure facilities on their company grounds. However, these pioneering efforts by companies such as Apple and Google in the USA and Bosch, BMW, and Siemens in Germany are nowhere to be found in countless industrial parks shared by small and medium-sized enterprises (SMEs) and Hüttenhain's research is focused on these companies in particular. "For several years, we've been exploring potential ways to transform commercial areas to provide a productive environment →

New Neighborhoods: the split between work, home, and leisure has been eliminated in Munich's Werksviertel.

→ for businesses and their workforces," says the researcher, who specializes in urban planning theories, and methods. Her work consciously includes those businesses that generate noise or odors. "We can't just consider the service or creative industries," Hüttenhain explains. "Dirty industries and craft enterprises are also essential to our livelihoods, which is what creates our prosperity and without which other jobs wouldn't even be possible."

Due to the problems caused by factories, architects used to insist on the spatial separation of residential and work areas, an attitude, which, as Hüttenhain explains, continues to shape our image of the city as well as the relevant legislation to this day, despite the fact that people have been aware of the disadvantages of long-distance commuting and a lack of urban facilities since the 1970s.

ENORMOUS AREAS THAT COULD BE COMPACTED

Whereas inner-city areas are already being rethought and designed in a functionally mixed way, purely commercial areas are still being neglected by urban planners, which is a pity as these areas, which are often extensive, could be more densely developed through the addition of parking areas and single-story commercial buildings, without using up more and more land. Last year, Hüttenhain and a team, which includes researchers from several universities, published a study on how service and industrial sites could be turned into laboratories and drivers for sustainable urban development. "We have to find ways of transforming industrial parks without displacing manufacturing businesses," Hüttenhain insists: "Urban planners and municipal policymakers must recognize that they not only need to take action on the issue of affordable housing, but also need to take steps to secure the future of the local economy."

Today, many companies are open to the idea of building apartments on their premises or in their immediate neighborhoods, provided that they receive assurances that these will not displace production facilities. The alternative would be new commercial areas on greenfield sites, which would mean more long-distance commuting and land consumption. "This," says Hüttenhain, "is not resource-efficient and, moreover, it is possible to find solutions for coexistence in terms of construction and space utilization, as recent projects have shown, as is impressively demonstrated by the International Building Exhibition 2027 City-Region Stuttgart (IBA'27)." Certainly, she continues, this is not yet a lifestyle model for everyone, but researchers and urban planners need to think ahead and consider such questions as what new building types might look like that facilitate coexistence in spite of emissions and what opportunities a different kind of mobility would create.

MORE ENTHUSIASM FOR EXPERIMENTATION IN URBAN PLANNING

Hüttenhain is hoping that Germans will be more willing to experiment and to "invest boldly in the future", which will require innovative spatial ideas and solutions that take account of resource efficiency and the circular economy and prioritize the long-term rather than just the short-term benefits. Urban planners and investors in Scandinavia and the Benelux countries are bolder, she notes, whereas in Germany: "We can hardly visit any built examples of multifunctional commercial districts, because many good ideas have not yet been implemented." Yet she is also hoping that her own research will soon help to change that. ↠

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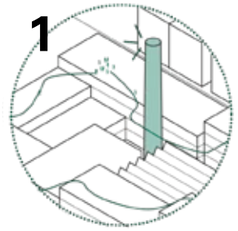
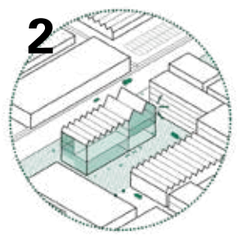
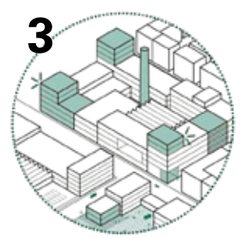
Illustrations/Photos: Britta Hüttenhain/Anna Kübler, Brigitta Stöckl, Stefan Werrer







Steps towards greater connectivity: educating the public through factory tours (1), promoting brand loyalty and acceptance through 'transparent' factories (2) or developing company sites into visitor experiences through the inclusion of hotels, parks and visitor centers (3).

A common language for connected devices

TEXT: Jutta Witte

Whether in the factory, at home or in the warehouse, the software platform from ThingOS, a spin-off from the University of Stuttgart, creates a rapid connection between smart devices, machines, and systems. The start-up, which was founded in 2018, has now successfully launched their IoT solutions on the market.

Intelligent floor: the ThingOS control software is installed under each tile to connect disparate systems.

The intelligent factory floor simultaneously acts as a sensor, display, and charging station. Industrial robots and self-propelled material boxes, which recharge their batteries without contact, are controlled by light signals while sensors record the weight. And the ThingOS control software is installed under every tile: "We enable communications between all systems," explains Thomas Kubitza, co-director of the startup. "What is on display here is the implementation of the platform idea in its purest form."

The name “ThingOS” stands for "Operating System for Networkable Things". What this refers to is a platform-driven operating system for the Internet of Things that networks intelligent devices regardless of manufacturer and technology. It can be accessed directly via an on-site hub, downloaded as an app from the cloud, or embedded directly in the electronics as firmware. The so-called communicating floor, which the start-up presented at Hanover Messe 2019 together with their collaboration partner and customer Bosch Rexroth, illustrates how the new software could be used in the smart factory of the future. But the fledgling company is also already providing connectivity in the networked home, interconnecting everything from light bulbs and wall switches to voice assistants.

CORE TECHNOLOGY ALREADY DEVELOPED IN PHD

ThingOS sells their platform and services to corporate clients either via a licensing model or as a white label, i.e., in the form of a pre-configured product, which the buyer then markets as its own software or hardware product. In terms of the IoT and its technical challenges, Kubitza instinctively got it right ten years ago, at a time when the Internet → of Things and its potential had not yet become widespread in the industrial sector. "Even at that time,” the software developer explains, “the central problem was fragmentation.” Rapidly establishing communication links and an efficient inter-operation between devices are still hampered by different technologies, standards, and protocols.

That is why Kubitza developed the meSchup IoT platform as part of his doctoral degree studies at the University of Stuttgart's Institute for Visualization and Interactive Systems (VIS), and thus the core technology of the current company. The meSchup platform quickly attracted interest from both industrial and commercial customers. Kubitza, who applied for his first business license at the age of 18 and, as he puts it, "was born with entrepreneurial genes," recognized the market potential and looked around for support. His institute colleague Patrick Bader was on board from the very beginning. Among others, the founding team, which later consisted of six members, was joined by Prof. Albrecht Schmidt, then head of the Human-Computer Interaction research group at the VIS.

Dr. Thomas Kubitza

"We enable communications between all systems.”

IDEAL CONDITIONS AT THE ARENA2036 RESEARCH CAMPUS

While ThingOS GmbH was not a "high flyer" with a market valuation in the billions, the technology-driven start-up needed no external funding from venture capitalists nor other investors and turned a profit right from the start. As Kubitza puts it: "We haven't grown rapidly, but our growth has been robust." ThingOS is "headquartered " in the University of Stuttgart's ARENA2036 research campus As far as the young entrepreneur is concerned, the approximately 4,700-square-meter factory building on the Vaihingen campus is "a super environment for innovations.” It simultaneously provides space for co-working and serves as an area for experimentation and a laboratory for interdisciplinary development projects that research institutes, large companies, SMEs, and start-ups wish to advance in the automotive and industrial sectors.

"New ideas emerge here during chats at the coffee machine and then quickly become reality," says Kubitza. It is also where that ThingOS won the "Start-up Autobahn" competition for new entrepreneurs. The company currently employs 15 people, the majority of whom are software development specialists. Kubitza is convinced that "if you want good products, you need a good team.” He believes in agile working methods, flat hierarchies, personal responsibility, and a modern corporate culture: "Working from home was standard practice for us even before the pandemic." The young talents who touch down here have to fit into this environment.

To be precise, ThingOS has already accomplished its "exit plan" a short time ago, as the start-up has been part of the Häfele Group since spring 2022, a medium-sized provider of smart home solutions, a sector in which Kubitza sees an opportunity to expand into new areas. When asked about the recipe behind this success story, he doesn't have to think long: "A great team, total commitment to the idea and a lot of stamina." ⇥

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Photos: ARENA2036 e.V./Corinna Spitzbarth Fotografie, ThingOS GmbH/Julian Ebert

Photos: ellis, private, SimTech

The goal of the ELLIS network is to advance research on artificial intelligence and machine learning in Europe.

"We are becoming visible at the European level"

INTERVIEW: Michael Vogel

Stuttgart is now an official participant in the European research excellence in machine learning network. The European Laboratory for Learning and Intelligent Systems (ELLIS) has chosen the location as a new unit. Founding directors Prof. Andreas Bulling and Prof. Ingo Steinwart discuss the importance of joining this network for the University.

Andreas Bulling is Professor of Human-Computer Interaction and Cognitive Systems.

Prof. Ingo Steinwart heads up the University of Stuttgart's Institute for Stochastics and Applications (ISA).

One gets the impression that there are currently innumerable research groups working on artificial intelligence. What's so special about the ELLIS network?
PROF. INGO STEINWART (IS) The ELLIS network is a grassroots movement, which grew out of European research on artificial intelligence and machine learning in December 2018 and is funded by the European Commission. The objective is to take a decentralized approach to this type of research in Europe and to collaborate more closely, including with the industrial sector. The ELLIS network now includes nearly 40 top institutions, such as the Universities of Cambridge and Oxford, ETH Zurich, the Technical University of Munich, and the University of Tübingen.
PROF. ANDREAS BULLING (AB) The special factor is that it is a pan-European network, which means that you can connect with other top-tier universities, which in turn facilitates mutual visits, for example, or doctoral student exchanges. The potential for Stuttgart as a research location is enormous.

Are there comparable networks in other research areas?
AB Not exactly. While other European initiatives, such as the CERN particle research laboratory, may be based on the same idea of promoting European research, their organizational implementation is completely different.

Did it take a lot of persuasion to get Stuttgart on board? After all, Stuttgart already participates in the Cyber Valley initiative.
AB ELLIS is a European project, so it complements Baden-Württemberg's Cyber Valley perfectly, which is why everyone in Stuttgart could recognize the benefits and were very enthusiastic about the idea right from the start. The unit in Stuttgart fits very well with the University's overall strategy, and in particular with its Excellence Initiative. It also reinforces Stuttgart's foothold in the Cyber Valley initiative.

How does an organization become a member of the ELLIS network?
IS You have to submit an application, which is followed by a stringent selection process. Certain formal criteria apply concerning, for example, the size of the intended ELLIS unit, in addition to which, researchers are evaluated individually to determine whether they meet the requirements for excellence. I have been involved in review processes for other units in the past, and in fact not all of the proposed researcher candidates for a new unit were accepted. →

→ What is the specific consequence of being accepted into the ELLIS network?
AB The University was required to agree to support the Stuttgart unit, both financially and, for example, by allowing ELLIS members more research time and will in fact be funding us with an extremely generous 150,000 euros each for five years. The money will be used to fund internship programs, and we are also planning a new lecture series as well as workshops and conferences. It also enabled us to hire a coordinator for the unit. No financial support is provided by the ELLIS foundation – but membership does raise our profile throughout Europe.
IS Such soft factors should not be underestimated! Together with the SimTech cluster of excellence in Stuttgart, we succeeded in filling a junior research group leader position that had already been advertised once without results before the Stuttgart ELLIS unit was founded.

What are the main research areas in which the Stuttgart ELLIS unit will be involved?
AB Four specialist fields that have to do with machine learning, namely Interactive Intelligent Systems, Natural and Programming Language Processing, Learning Theory, and Robot Learning.

Will other researchers be able to join the Stuttgart unit?
IS The possibility exists, yes. Our selection criteria are closely aligned with those of the ELLIS network, whereby excellence is of central importance. ↠

THE MEMBERS OF THE STUTTGART ELLIS UNIT

PROF. DR. ANDREAS BULLING, Institute for Visualization and Interactive Systems, University of Stuttgart

DR. PAUL BÜRKNER, Cluster of Excellence Data-Integrated Simulation Science SimTech, University of Stuttgart

DR. KATHERINE KUCHENBECKER, Max Planck Institute for Intelligent Systems Stuttgart

PROF. DR. MATHIAS NIEPERT, Institute for Parallel and Distributed Systems, University of Stuttgart

PROF. DR. MICHAEL PRADEL, Institute of Software Engineering, University of Stuttgart

APL. PROF. DR. SABINE SCHULTE IM WALDE, Institute for Natural Language Processing, University of Stuttgart

PROF. DR. STEFFEN STAAB, Institute for Parallel and Distributed Systems, University of Stuttgart

PROF. DR. INGO STEINWART, Institute for Stochastics and Applications, University of Stuttgart

PROF. DR. THANG VU, Institute for Natural Language Processing (IMS), University of Stuttgart

Prof. Steinwart and Prof. Bulling giving a presentation about the network

Students at the ELLIS launch event in July

THE FOUR MAIN RESEARCH AREAS OF THE STUTTGART ELLIS UNIT

1 **Interactive Intelligent Systems:** These research activities are aimed at developing intelligent systems with which humans can collaborate in as natural a way as possible. In particular, so-called user modeling is central to successful human-machine interaction: is a person hectic or tired? Is a trainee surgeon holding a surgical instrument in the correct manner? does a machine correctly understand the intentions of a human with whom it has to collaborate on a task?

2 **Natural and Programming Language Processing:** Both the machine processing of human language and of programming languages is a highly active field of research in Stuttgart. Speech recognition already works amazingly well, but things get difficult when such things as accents or background noise need to be dealt with. When it comes to programming languages, on the other hand, researchers are no longer interested in formally typing in code, but rather want to be able to enter it using natural language, or, for example, to use machine learning methods to automatically find errors in program code (see also page 48)

3 **Robot Learning:** As a research location, Stuttgart is strong in hardware engineering, using machine learning to develop intelligent robot systems capable of operating autonomously in complex environments. For example, depending on the specific task, autonomous robots must be able to grip objects either gently or firmly. This focus will also be represented by two additional W3 professorships for "Machine Learning and Robotics" and "Autonomous Systems," for which the appointment procedures are currently underway.

4 **Learning theory:** it is crucial to find the right parameters when it comes to machine learning, to ensure that processes deliver the right results quickly and reliably. Conceptually, one can think of these parameters as adjusting screws, whereby one has to select and adjust the right ones from millions of possibilities – a far from trivial task. In order to be able to improve systems, a deeper theoretical understanding of the underlying mathematical processes is required.

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Photos: Katherine J. Kuchenbecker, Perceptual User Interfaces

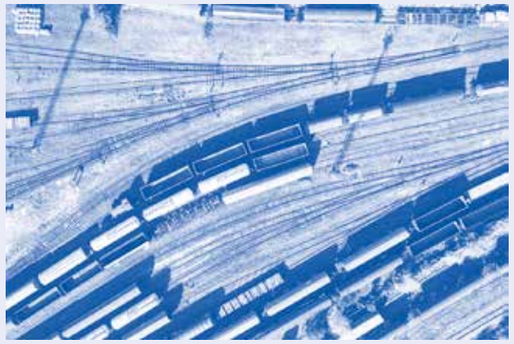
CANSU KÖSE

A HUGE FAN OF THE STUTTGART S-BAHN

TEXT: Miriam Hoffmeyer

During his studies, structural engineer Cansu Köse developed a fascination for highly complex networks and security technology. She currently works for the Thales technology group.

The questions that Cansu Köse asks herself every day all begin with "what if...". For example, she might ask herself what would happen if a software or hardware error were to unblock an operating system in an interlocking tower that was undergoing maintenance or where else such an error could occur and what could be done to prevent it. "We theorize about a very large number of use cases," Köse explains, "because many sources of danger are not immediately obvious." The young structural engineer, who grew up in Istanbul and studied in Stuttgart, specializes in interfaces between control and operator interfaces and other electronic systems. She has been working in the Safety Department of the Thales Deutschland technology group in Ditzingen for the past four years. Her team specifies the requirements with which safety-relevant systems and products must comply in accordance with European standards before they can be used in the rail transport system. "We also specify the requirements that need to be tested and the hazard analysis methods that need to be used to comply with the applicable safety standards," says Köse who first became fascinated by highly complex networks and security technology during her bachelor's studies at the University of Stuttgart in 2011, during which she spent a semester abroad at Sakariya University. "I was immediately thrilled by how quickly you can get anywhere on the S-Bahn here. Back then in Istanbul, you had to rely on buses and ferries to get from the Asian side to the European side." After graduating with a →



Photos: private, IStock

Cansu Köse

"We also specify the requirements that need to be tested and the hazard analysis methods that need to be used to comply with the applicable safety standards."

→ bachelor's degree, Köse successfully applied to study for a master's degree at the University of Stuttgart in 2014. "I settled in very quickly, partly because of the large expatriate Turkish-speaking community here. I have also come to like the fact that the city is so much smaller than Istanbul. The only thing I miss is the sea."

MENTOR FOR OTHER FOREIGN STUDENTS

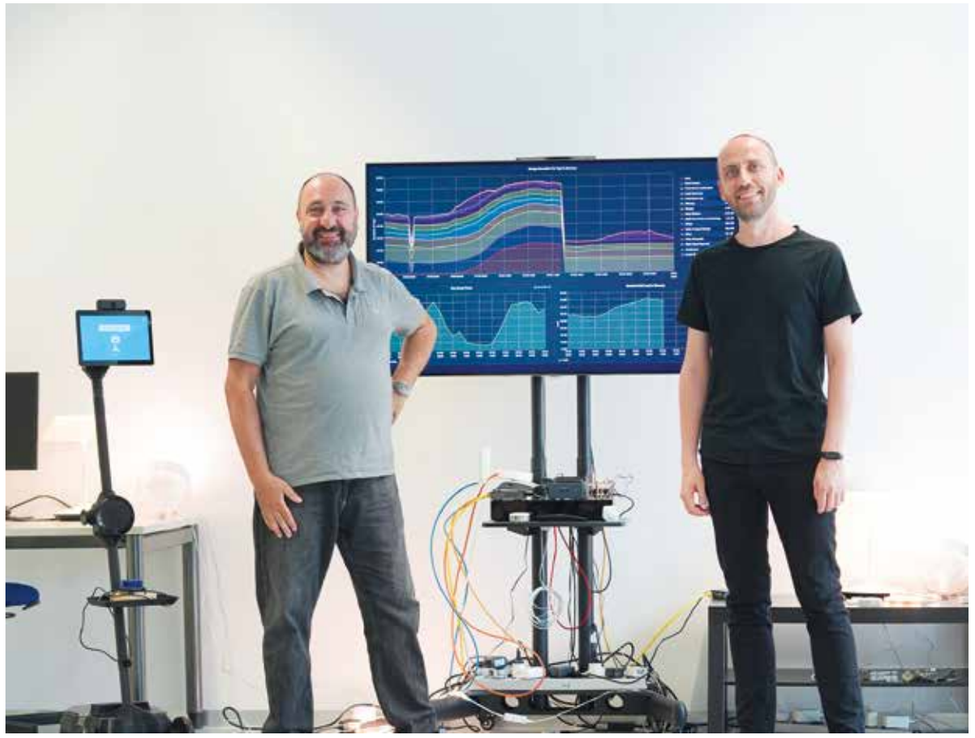
To finance her studies, she first worked as an academic assistant at the University of Stuttgart's Institute of Railway and Transportation Engineering (IEV), and later as a student trainee at Thales Deutschland. In spite of this, Köse always found time to act as a mentor and "buddy" for international students. "When I first flew to Stuttgart, it was also my first ever trip abroad," she recalls It was comforting to know that my buddy would be there to meet me at the airport and help me with my arrival. I was eager to return that support and also really enjoyed getting to know a lot of international students and their respective cultures."

For her master's thesis, Köse studied signal transmissions between trains and the control center during semi-automated driving, which must take place continuously according to the European standard ETCS Level 2 (European Train Control System). She was able to start her current job even before her final presentation. Since then, she and her departmental head have given guest lectures on safety-related topics at the IEV once a year, at her initiative: "The students are very interested in some aspects of our work and I'm happy that it enables me to keep in touch with the University." ⇥

Shared passion for smart buildings

TEXT: Michael Vogel

Ilche Georgievski and his doctoral supervisor, Marco Aiello, have been conducting research together for over a decade. They first met in the Netherlands, and are currently working at the University of Stuttgart, where they are looking for ways to operate intelligent buildings in a sustainable manner.



Marco Aiello (l.) and Ilche Georgievski in their research laboratory

Both come from Southern Europe, both have spent half their lives abroad, and both are computer scientists. And both are conducting research at the University of Stuttgart into how to make buildings smart in order to make them more sustainable. Prof. Marco Aiello heads up the Service Computing Department at the University of Stuttgart's Institute of Architecture of Application Systems (IAAS), while his colleague, Dr. Ilche Georgievski, is responsible for the Smart Energy Systems work area in the same department. "Modern buildings are equipped with a network of sensors and actuators that monitor the operation of the property," says Aiello. "But the resulting flood of data is not sufficient to explain how to operate a building in a more sustainable way." This is where Aiello and Georgievski come in. The two computer scientists have known each other for years; Aiello was even Georgievski's doctoral supervisor at the Imperial University of Groningen in the Netherlands.

"We ultimately want users to be able to express their needs in everyday language, and for the smart building to independently determine the best way to meet those needs," Aiello explains. So, for example, rather than "lights off and blinds up" to enjoy the daylight, the user would simply say "brighter, please." And instead of "please lower the temperature for three days" because a room is unused, you would say "please keep the room air-conditioned in the most sustainable way possible." "So I just say what I want to happen, and the building does the rest," says Aiello. It might be acceptable, for → example, to use more energy for air conditioning at certain times of the day and in certain weather conditions because the energy is generated by the photovoltaic system on the roof, which means that the overall CO_2 emissions would still be low. On rainy days, on the other hand, this higher energy consumption might not be acceptable because the power would have to be supplied from less sustainable sources. People who use a building as an office space, for example, don't want to have to deal with such decisions.

USING AI PLANNING TO FIND THE BEST APPROACH

In the course of various research projects, Aiello's team have built a number of demonstrators in areas such as university buildings, a cafeteria, and a data center. His team uses artificial intelligence (AI), or more precisely AI planning methods, to deal with the plethora of ways to achieve a given goal at a given time in a given situation. "By contrast with machine learning," Georgievski explains, "where the goal is to classify a vast amount of data and predict outcomes in the absence of explicit instructions, AI planning is based on a symbolic representation of the world." One formulates a goal, which could be achieved in many different ways. "Each potential approach is made up of many individual steps, each of which can be assigned a cost in advance." These could be direct costs, such as the price of electricity per kilowatt hour or a given quantity of CO_2 emissions. But there could also be hidden costs, such as a loss of time or lower productivity.

"If there is an optimal sequence of individual steps, AI planning can be used to find it," Georgievski explains: "Once the best way to achieve the goal has been determined, it then serves as the basis for controlling the actuators within the building. "Unfortunately, the number of potential solutions is so large that we have to come up with clever ways to arrive at a result in the most efficient manner." People would find it difficult to accept an intelligent building if, for example, it took an entire minute to calculate how to optimally adjust the room lighting.

Aiello has been interested in smart buildings for two decades. The Italian studied computer science in Rome and earned his doctorate in logic at the University of Amsterdam in the Netherlands. During an internship at Apple in the USA, he took the advice of his supervisor, who "advised me to pursue a doctorate in order to develop a really →

PROF. MARCO AIELLO

"So I just say what I want to happen, and the building does the rest."

A dashboard displays various building systems data.

Photos: private

Prof. Marco Aiello delivering a lecture

→ profound understanding," Aiello recalls. Following several years as a young researcher at the University of Trento, he habilitated in applied computer science at the Vienna University of Technology. He returned to the Netherlands in 2006, where he took up a position at the Imperial University of Groningen, first as an associate professor and then, in 2012, as a full professor. He accepted an appointment at the University of Stuttgart in 2018 but still holds an honorary professorship at the Imperial University of Groningen. "None of this was planned," he says: "On several occasions, I assumed that this would be the final relocation. But then a new and interesting opportunity would present itself and ..."

Aiello aptly describes himself as a "European nomad" on his Twitter account. This is also reflected in the linguistic diversity of his family. He is married to a German but their kids were born in the Netherlands, where they spent some of their school years. Both parents speak to the children in their respective native languages but English is the preferred language if the whole family is involved in a conversation.

SHARED ROUTE FROM GRONINGEN TO STUTTGART

Georgievski, who was born in a place now known as North Macedonia, first met Aiello, his doctoral supervisor, in Groningen. "After graduating from high school, I told my parents that I wanted to study abroad," he says. Specifically, he wanted to study in a country whose degrees are automatically recognized throughout Europe. He moved to Slovenia to study computer science. As he could not speak Slovenian, he started learning the language a year earlier and dived in at the deep end. "After that," Georgievski continues, "I wanted to get a PhD, and looked around for a European country where English is the standard language in academia." The Netherlands was an obvious candidate. He looked at potential PhD. supervisors, read their publications, and, among others, submitted an application to Aiello, which was met with success.

He received his PhD from the Imperial University of Groningen, whereby a significant part of his doctoral studies was focused on automation algorithms for smart buildings. Several of his colleagues founded a start-up under the leadership of Aiello, whose goal was to develop software solutions for sustainable buildings, and Georgievski joined them. The start-up was acquired by a company in 2020, by which time Georgievski had already left. "I spent a year with the startup, which was a very educational and labor-intensive period," he recalls. "However, it was also during this time that I realized how much I appreciate the freedom of research. I struggled to comply with what I thought of as overly restrictive requirements from corporate clients." Georgievski told his former PhD supervisor that he would be quitting the startup and going back to academia. Aiello replied that he would be moving to Stuttgart, and asked Georgievski if he would like to come with him. "I had already been thinking that, if I wanted to pursue an academic career, I would need to take up a position in which I could carry out my postdoctoral studies," says Georgievski. The University of Stuttgart presented him with precisely such an opportunity – and he had a good relationship with Aiello, which explains why they both took up their positions at the IAAS at the same time in April 2018. ⇥

Dr. Ilche Georgievski

"I also realized hat I value the freedom of research."

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Photos: private

Universität Stuttgart

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PUBLISHER
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