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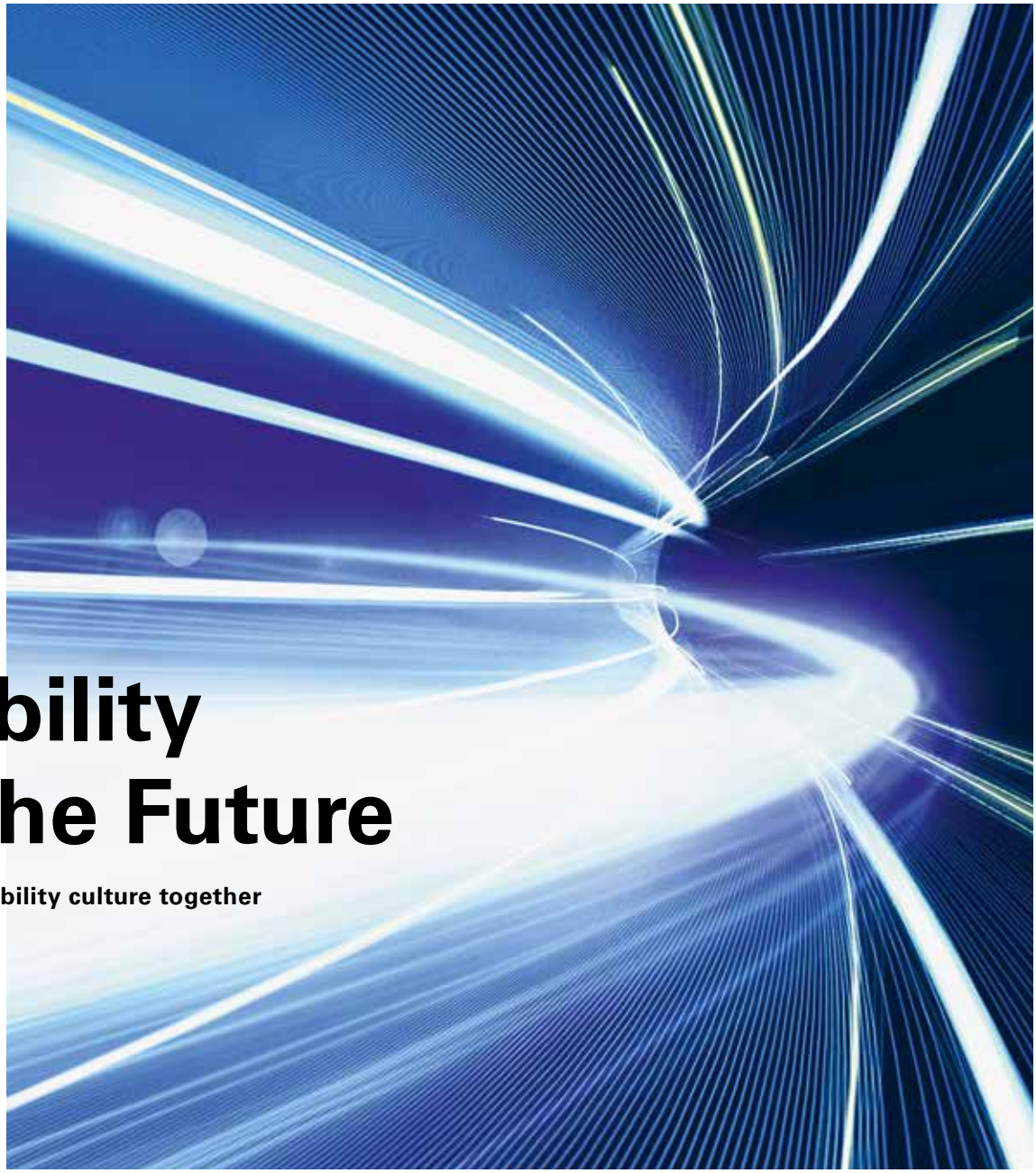

Mobility of the Future

Shaping mobility culture together

Real laboratory
Science meets society

Human models
Simulations for greater safety

New territory
The emission-free campus is coming

Prof. Wolfram Ressel

“The challenges involved in developing intelligent and sustainable mobility for our future society are great.”

Dear Reader,

Photo: Matthias Schmiedel

Prof. Wolfram Ressel
Rector of the University of Stuttgart

“Mobility guarantee” is a term being used by vehicle manufacturers and transport service providers to refer to their pledge to their customers that they will be provided with an alternative means of transport should a vehicle or means of transport fail. However, rather than the search for future-oriented mobility alternatives being based on vexatious breakdown situations, the current focus is on scientific research and application-oriented technology transfer relating to the question of how people and goods will be transported to the desired destination in the future. Because the challenges involved in developing intelligent and, above all, sustainable mobility for our future society are great. Nor is it yet possible to predict how the Covid-19 pandemic will affect our mobility over the long term or which of the crisis factors will influence people’s travel behavior.

This issue of “forschung leben” presents an overview of the University of Stuttgart’s initiatives and various research activities relating to future mobility, from the “Mobility of the Future” innovation campus and the “Real Laboratory for Sustainable Mobility Culture” to concepts for an emission-free campus, autonomous vehicles, electric aircraft and innovative energy systems. The mobility concepts that will be derivable from the research being carried out at the University of Stuttgart are diverse and very promising and will form the basis for mobility guarantees of the future.

Best regards,

p. 34

EXPERIENCE RESEARCH

Mobility in the field of 3D printing

p. 16

NEW TERRITORY

The car-free campus is coming

p. 26

EXPERIENCE RESEARCH

Into the city – experiments in the Real Laboratory

Photos: pp. 1 & 92 Getty Images/Yuichiro Chino, p. 4 Uli Regenscheit, p. 5 Max Kovalenko, University of Stuttgart

NOTE PAD

PRIZES

THE EUROPHYSICS PRIZE 2020

Prof. Jörg Wrachtrup, Director of the University of Stuttgart's 3. Physikalisches Institut won the European Physical Society's "Europhysics Prize 2020" in the Condensed Matter category. This world-renowned award recognizes Wrachtrup's pioneering achievements in the field of quantum coherence in solid state systems and its applications in sensor technology, particularly for research into the optical and spin properties of nitrogen gaps in diamonds.

THE RUDOLF KAISER PRIZE

The Physicist **Dr. Tim Langen** of the University of Stuttgart's 5. Physikalisches Institut has won the Rudolf Kaiser Prize 2019, one of the highest endowed prizes for up-and-coming researchers in the natural sciences. It is awarded annually to an outstanding young researcher working in the field of experimental physics. Langen was awarded the prize for his experimental work on superfluidity and supersolidity in dipolar quantum gases, and in particular for his observation (the first ever) of a state of matter that combines the crystalline structure of a solid with the smooth flow of a superfluid.

THE EUGEN AND ILSE SEIBOLD PRIZE

The German Research Foundation's (DFG) Eugen and Ilse Seibold Prize was awarded to **Prof. Hidenori Takagi** of the University of Stuttgart's Institute for Functional Matter and Quantum Technologies (FMQ) and materials physicist at the Max Planck Institute for Solid State Research. The prize, which is endowed with 15,000 euro, is awarded for successful contributions to German-Japanese academic and cultural exchanges. Takagi is well known for his many contributions to the field of materials physics and has published pioneering work on metal-insulator transitions, high-temperature superconductivity and quantum magnetism. He actively promotes German-Japanese collaboration by collaborating closely with research groups at the University of Tokyo, where he still holds a professorship.

NEW GERMAN RESEARCH FOUNDATION (DFG) PRIORITY PROGRAM

GETTING INVOLVED IN THE IBA

The International Architecture Exhibition (IBA) will be hosted in Stuttgart and the surrounding region in 2027. In addition to the City of Stuttgart, IBA partners include the Verband Region Stuttgart (the political entity of the Stuttgart Region), the Stuttgart Regional Economic Development Corporation, the Baden-Wuerttemberg Chamber of Architects, and the University of Stuttgart.

Prof. Klaus Jan Philipp, Head of the Institute of Architectural History, is the university's representative for the 2027 IBA. Research assistant Lena Engelfried is assisting him in this task, working at the interface between the University and the IBA. Numerous ideas for the University's participation as well as projects, from smaller exhibitions to showcase buildings, are being discussed. As Prof. Philipp explains, there is a very good fit between the University's "Intelligent Systems for a Sustainable Society" vision and the IBA's focus which includes sustainability, ecology, mobility, social affairs, and climate. "These future-oriented topics go far beyond construction as such."

From the interaction between biceps and triceps to processes within the liver and brain, computer-aided models in the field of medicine can help to diagnose diseases more accurately and treat them in a more personalized manner. However, this potential is still little used because cells, and tissues such as muscles and organs, have mainly been considered in isolation up to now. A new DFG priority program will interconnect these models to gain a better understanding of and predict the complex interactions between the various structures and scales as well as their functions. The interdisciplinary research network known as "Robust interlinking of biomechanical continua in silico models for active biological systems as a preliminary stage for clinical applications" was initiated by Professors Oliver Röhrle and Tim Ricken of the University of Stuttgart's Institute for Modelling and Simulation of Biomechanical Systems and Institute of Statics and Dynamics of Aerospace Structures respectively, with the participation of the University Hospital of Rostock, the Friedrich–Alexander University Erlangen–Nürnberg, and the University of Cologne.

RESEARCHING COVID-19 2020

The Covid-19 pandemic has been overshadowing people's everyday lives, including at the University of Stuttgart, since March 2020 With just a few exceptions, the campus remained empty, and university operations had to be reconsidered. At the same time, numerous research and support initiatives have been launched to help to manage the pandemic.

FACE SHIELDS

Scientists at the ARENA2036 research campus and the neighboring Institutes at the University of Stuttgart.'s Vaihingen campus are making use of facilities that are typically used for the construction of prototypes for automotive, aerospace, and engineering applications, to make 3D-printed protective visors to support people working in clinical settings and medical practices. 10,000 face visors had already been produced by mid-June, which were sent to the partner university in Bergamo, to Chile and to a refugee camp on the Greek island of Lesbos, among other places.

The objective of a collaboration between Campus Schwarzwald and the University of Stuttgart's Institute of Industrial Manufacturing and Management (IFF) and other partners is to produce some 100,000 face shields per week. The face shields can be produced quickly and easily and in large quantities; they are extremely light and can be worn over glasses.

The University of Stuttgart's Institute of Polymer Technology (IKT) produced the visor material as well as complete face shields. A bio-based and biodegradable polylactide (PLA) is used both for the plastic sheet and the filaments used for 3D printing. A particularly clear plastic sheet can be produced in any shape required, thanks to the specifically adjusted extrusion process.

MORE EFFICIENT COVID-19 TESTS

The Technical University of Braunschweig, the University of Stuttgart, the Junge Academy, and the company Arctoris have jointly addressed the issue of efficient testing. An interdisciplinary team of mathematicians, computer scientists, and physicians has developed a decision support tool that calculates which procedure in a positive sample pool is able to identify all persons suffering from Covid-19 as effectively as possible. Their simulations show that the pool-based test procedures used in Germany can be about eight times more efficient than individual tests.

DISINFECTANTS

When disinfectant supplies ran out in the spring, pharmacies, pharmaceutical companies and authorities were given permission to produce disinfectant solutions based on isopropanol or ethanol, but there were insufficient quantities of the raw materials available. This is why the University of Stuttgart's Faculty of Chemistry produced urgently required hand disinfectant on a large scale for and in collaboration with the Kassenärztlichen Vereinigung Baden-Württemberg to bridge bottlenecks at the peak of the Covid-19 crisis.

CALCULATION MODEL FOR CONTACT RESTRICTIONS

But which Covid-19 restrictions are necessary, and which lockdown regulations could be relaxed? This is difficult to estimate due to the uncertain and dynamic data situation and the complexity of the infection patterns and the measures to combat them. Researchers at the University of Stuttgart's Institute for Systems Theory and Automatic Control have developed a computational model with which adaptive measures can be determined much more reliably when there is uncertainty than has hitherto been the case. It calculates the best strategy for the future based on a large amount of data and numerous strategies, but this is then only applied for a few days. This calculation process is then communicated with updated parameters and the optimal strategy is determined once again. This results in a continuous process in which the original strategy is continually adapted and several prediction models can also be taken into account.

RISK MANAGEMENT IN SUPPLY CHAINS

One consequence of the Covid-19 pandemic, which had a serious impact on the economy, was the collapse of global supply chains. Prof. Andreas Größler of the University of Stuttgart's Institute of Business Administration, and his doctoral student Marc Wiedenmann conducted research into what companies could learn from the crisis and what solutions should be implemented. The researchers regard supply risk management as a potential solution. "The crisis," they say, "makes risk management an essential part of every corporate and supply network." Interdisciplinary teams, they continue, would have to find ways to identify and assess supply risks and to develop action strategies, to enable companies to react in the best possible way.

Supply Risk Management

More information about the University during the Covid-19 pandemic

Photos: p. 6 David Ausserhofer, University of Stuttgart/5. Physikalisches Institut, Hidenori Takagi, p. 7 University of Stuttgart/ILEK, Max Kovalenko, p. 8 Max Kovalenko, p. 9 University of Stuttgart

3 QUESTIONS FOR

THE GREENTEAM

An electric motor instead of a roaring internal combustion engine ... and in a racing car? That might sound crazy but it was precisely this idea that got the University of Stuttgart's GreenTeam to the starting line a good ten years ago. Since then the students have stood unchallenged in the top ten of the global ranking list for electric racing cars and, with Team Driverless, are also pushing the boundaries of fully autonomous driving. Marius Goletz and Laura Kleckner present an overview of the project.

What does the GreenTeam do?
The GreenTeam is a club with about 30 to 50 student members and we develop and build an electric Formula Student racing car ever year. We do everything, from conceptualization to design, production, assembly, and testing, ourselves. We've also been converting scrapped cars into autonomous racing cars for the driverless competition since the 2016/2017 season, whereby our focus is increasingly on sensor technology and software systems. And, last but not least, we have to defend our technical implementations in front of an expert jury in the so-called static disciplines, as well as present a business plan and submit a cost report. In short – we never get bored.

What have been your greatest successes?
So far our most successful racing years have been for Team Electric, who achieved overall victories and placements at almost every event with the E1 and E8. But what counts for us is not just the overall victory at various events, but also the fact that we're using motors that we developed ourselves and that we produce as many of our own components as possible. We managed to score points in last season's Driverless class in Spain, especially in the static disciplines, where we came 3rd overall.

What's next for the car?
What the enforced break due to the Covid-19 pandemic means for Team Electric is the opportunity to return to the development phase, revise important work packages, perform additional tests and make a start on other projects. Often there is no time for all that in normal seasons.

We are fortunate that, in theory, we havea working vehicle in the workshop for the Driverless class. We now want to test and optimize our software in the car.

The video of the GreenTeam's 10th anniversary is available on YouTube.

Photo: the University of Stuttgart's GreenTeam

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Carrying out critical inspections: Prof. Markus Friedrich measures mobility behavior.

Mobility on the test bench

TEXT: Judith Reker
PHOTOS: Sven Cichowicz

Name one of the biggest challenges for the transport transition? According to transport planner Prof. Markus Friedrich, one answer would be: “bold policy that isn’t solely reliant on incentives.”

Transport researcher Prof. Markus Friedrich is looking into the effects of new mobility solutions, such as automated vehicles, cable cars, cargo trams and on-demand services, on the future of transport. However, his efficacy analyses suggest that numerous innovations have undesirable side effects and do not really contribute to solving our current transport problems. “Those who question new approaches”, says Friedrich with a smile, “are quickly perceived as Luddites, which is a label that nobody likes to be given. Yet we need to avoid wishful thinking and undesirable developments.”

His expertise is, however, in demand, for example as a member of the German Federal Ministry of Transport and Digital Infrastructure’s scientific advisory board. Friedrich, who holds a degree in civil engineering, has been head of the Chair for Transport Planning and Traffic Engineering at the University of Stuttgart’s Institute for Road and Transport Science (ISV) since 2003. Among other things, he is currently working with an interdisciplinary team of researchers from the fields of civil and traffic engineering, environmental protection technology and cybernetics to investigate ways of measuring mobility behavior in a precise manner. Testing and evaluating novel traffic concepts is an integral part of his work in addition to research and teaching.

PUBLIC TRANSPORT – A SYSTEM THAT BREATHES

Friedrich’s evaluations can sound devastating. Take car sharing, for example: “When, in a few years’ time, we have access to a car-sharing vehicle whenever we want,” he explains, “we’ll use it just like a car. So, we’ll have fewer cars, but we won’t drive fewer kilometers. But the kilometers driven are what people perceive as traffic. If ten cars pass you by, it makes no difference if it’s the same car or ten different ones.” The traffic planner is also critical of the concept of ridesharing, or organized carpooling: “Many ridesharing service users will come from public transport and it will be difficult to achieve a higher rate of occupancy than in private car transport. The best form of ridesharing,” he adds, “is public transport.” →

→In Friedrich's opinion, public transport is the most efficient means of urban transport, which he describes as a "breathing system", because its capacity is – at least at the local transport level – scalable to a large extent. Everyone gets a seat during off-peak hours, but some passengers have to stand during peak hours, which as Friedrich explains, means that the passengers contribute to a significant temporary capacity increase that no other means of transport can provide. "The tailbacks occur inside the means of transport, not on the road, which is good for the city, but stressful for the passengers." So if one really wants sustainable mobility with fewer vehicle kilometers, one has to be "brave enough to say: 'Because we like our city, we're prepared to stand up for it – at least during rush hour.' That's the only way that major cities work." Any individualization, he goes on, would make the transportation system more comfortable, but not more efficient. "Now," says Friedrich, "all we have to do is to ensure that this supposedly outdated traffic concept becomes accepted as an intelligent solution and implemented in as optimal a manner as possible."

The complex topic of public transport service planning is the subject of the "Integrated Planning in Public Transport" research project, in which the ISV is collaborating with seven other universities. The aim of the project, which has been funded by the German Research Foundation since 2015, is to combine planning procedures with mathematical optimization methods to develop the best possible public transport network. Because, among other things, there is a very large number of potential solutions for a route network, this presents a challenge. By way of example, Friedrich asks the apparently simple question: what is the optimum number of bus stops? "On the one hand, passengers want to live as close as possible to a bus stop to minimize the distance they have to walk, which necessitates a high density of bus stops. But, on the other hand, once they're on the bus, the same people soon tire of the bus stopping all the time."

AUTONOMOUS CAR TRAFFIC SCENARIOS

Friedrich and his team shed some light onto another aspect of mobility in the CoEXist project, which they completed in April 2020. The purpose is to help traffic authorities and municipalities prepare for the approaching new era, when automated vehicles will start using the roads alongside conventional ones. The three-year project was funded through an EU Framework Program for Research and Innovation known as Horizon 2020. In addition to the City of Stuttgart and the ISV, the cities of Milton Keynes in Great Britain, Gothenburg in Sweden and Helmond in the Netherlands as well as other partners were involved in the project. Among other things, the ISV examined how automated vehicles might affect demand. The researchers asked the question: what happens in the initial stage of automation when drivers perceive driving time as less problematic because of assistance systems such as the congestion assistant? Answer: the car becomes more attractive compared with public transport.

The team also modelled the next stage and asked how the demand for car traffic would change if we were able to drive fully autonomously and nobody needed a driving license any more, i.e., if even children could be driven to the sports club by themselves? The short answer is that demand would increase. "Every scenario results in more car traffic", says Friedrich and points out that: "because automated cars would be better, we would use them more often, which, however, is not compatible with the ideas of most municipalities, whose goal is to reduce car traffic." →

Serves everybody: public transport remains unsurpassed in terms of the environment and less traffic.

Well distributed: most people in Stuttgart live within 300 meters of a bus stop.

→Friedrich is hoping that the insights he has gained could help to educate politicians about the fact that even automated vehicles are not sustainable per se. "Behind every kilometer driven by cars – including electric cars – there is a certain amount of energy consumption. The only way that automated, electric vehicles could contribute to solving urban traffic problems would be if we were to use their properties intelligently. Automated vehicles, for example, are better able to comply with rules than humans, and, unlike combustion engines, electric drives are also efficient at low speeds". These properties make it possible to design urban road networks not only to include 30 mph zones, but also continuous low-speed networks. This would enable "slow modes", such as bicycles and e-scooters to share the road space with cars.

However, Friedrich sees striving to achieve political solutions as the greatest challenge: "It is the job of politicians to establish the framework." This, he goes on, includes incentives for sustainable mobility behavior in addition to restrictive measures. "Those promising less traffic and lower CO_2 emissions cannot keep their promises by making cars cheaper, for example by offering a purchase premium. Electric cars are still cars that take up urban space and compete with public transport". Friedrich is convinced that: "We'll get the traffic we want, so we ought to be thinking about what it is we want." Transport research can then point out ways of achieving this objective. →|

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One day in the future, the driverless Campus Shuttle will connect the multi-story carpark with the campus buildings.

The car-free campus is coming

TEXT: Andrea Mayer-Grenu

The MobiLab on the Vaihingen Campus is a real-world laboratory for intelligent, emission-free mobility. Researchers are exploring the possibilities of an emission-free campus with an innovative traffic concept based mainly on the use of shuttle buses and e-scooters.

Sparkling car roofs as far as the eye can see. Anyone who strolls through the University of Stuttgart Vaihingen campus in fine weather will immediately see why previous mobility concepts are being phased out: half of the approximately 5000 staff members and nearly 20 per cent of the 23,000 students on campus get there by car. Not only does that produce harmful nitrogen oxides and the climate killer CO_2, it also takes up a lot of space for parking – space that could be being used more sensibly.

But private cars on the Vaihingen campus will soon to be a thing of the past. Mobility Living Lab, or MobiLab for short, is an innovative traffic concept the aim of which is to achieve a car- and emission-free campus. At the same time, research into the mobility of the future will be carried out there. "The MobiLab", says Prof. Wolfram Ressel, Rector of the University of Stuttgart, "will be a multifaceted real-world laboratory which will combine research into new forms of traffic development, novel means of transport, electric drive systems as well as intelligent energy storage and distribution systems." It garnered 300,000 euro in prize money in an ideas competition organized by the state of Baden-Württemberg, which will also be funding the implementation of MobiLab as an exemplary state-wide lighthouse project with a further 3.5 million euro over the next two years.

BATTERY CHARGING ON THE MOVE

A multi-story car park that will span the B14 freeway will be the gateway to the car-free campus. Around 3000 parking spaces are planned, but the highlight of the building will be on the roof where a solar system will produce electricity, which will be used to charge the parked cars as well as the campus shuttles. "The campus shuttles", as Prof. Hans-Christian Reuss of the University of Stuttgart's Institute of Automotive Engineering explains, "will be self-propelled, i.e., autonomous shuttle buses of various sizes with electric drives and intelligent sensor technology. They'll connect the multi-story car park, as well as, incidentally, the central S-Bahn station, with the University buildings, which are spaced far apart." A regular service with fixed stops is planned initially and an on-demand service is to be added later, where it will be possible to conveniently book the destination in advance via a cell phone app.

Part of the shuttle route will include a research road in which electrical coils and electronic circuits, designed to enable the inductive charging of the vehicles whilst driving, will be installed. Various scenarios are currently being tested. Of particular importance is the position of the vehicle during the charging process, as this affects the energy transfer, as Prof. Nejila Parspour of the Institute of Electrical Energy Conversion explains. "We→

→are therefore investigating the tolerances of different charging systems, lane-keeping systems and autonomous navigation with a view to improving the ecological balance of electric vehicles."

If it were possible to develop a close-meshed inductive charging infrastructure that could enable vehicles to be charged on the move – on the freeways for example – the range could be significantly increased for any given battery capacity. On the other hand, it would also be possible to use low-capacity batteries, which would save resources during production. To optimize charging processes, avoid grid bottlenecks and reduce the impact on voltage quality, the charging infrastructure would be integrated into the electrical distribution grid via intelligent solutions. Prof. Krzysztof Rudion of the Institute of Power Transmission and High Voltage Technology is collaborating in the project and is looking at smart grid approaches.

However, not every one of the 40,000 daily strolls around the campus can be replaced by a trip on the autonomous Campus Shuttle, which is why the buses will be supplemented by campus scooters. Initially, a start-up will set up an e-scooter rental system, into which autonomous e-scooters will be integrated successively. These are being developed by another start-up in collaboration with the University of Stuttgart's Institute for Systems Theory and Automatic Control (IST) in the Autonomous Micro-Mobility at Campus Uni Stuttgart (AMICUS) subproject. The autonomous e-scooter also drives without a driver, as if by magic and without tipping over, of course. As the head of IST, Prof. Frank Allgöwer explains, modern control technology is behind all of this: "the e-scooters will be kept in balance, even in the event of malfunctions, by means of novel specially developed control strategies and will use sensors to recognize their surroundings, avoid obstacles and navigate autonomously." Machine learning will also enable the e-scooters to be distributed around the campus in an optimum manner based on user requests, and a distribution algorithm will ensure the best possible route planning. This will make it possible to keep the fleet small. And because the scooters will also be able to drive to the nearest charging station without a driver, the difficult task of the so-called juicers who, elsewhere, have to go out at nights to collect scooters for refueling, will no longer be necessary.

BEHAVIORAL CHANGES ARE NEEDED

Many of the MobiLab components still need to be researched and tested, but implementation has already begun. "It's easier to develop a traffic concept than to implement one," says MobiLab coordinator Prof. Markus Friedrich. "For the MobiLab to be successful we will need to change the framework conditions for everyday mobility to the campus. There is huge support for more bicycle parking spaces, the Campus Shuttle and the Campus Scooter. But a car-free campus will also require behavioral changes." Not all staff and students would like it if they had to pay for parking and if, in the medium term, there were no more parking spaces directly in front of the campus buildings, but only in a central car park. "Experience with pedestrian zones shows us that there is resistance prior to implementation, but as soon as we get used to the benefits of the new setup, everyone comes to like it." ⇥

The MobiLab concept on film

Video of the autonomous e-scooter

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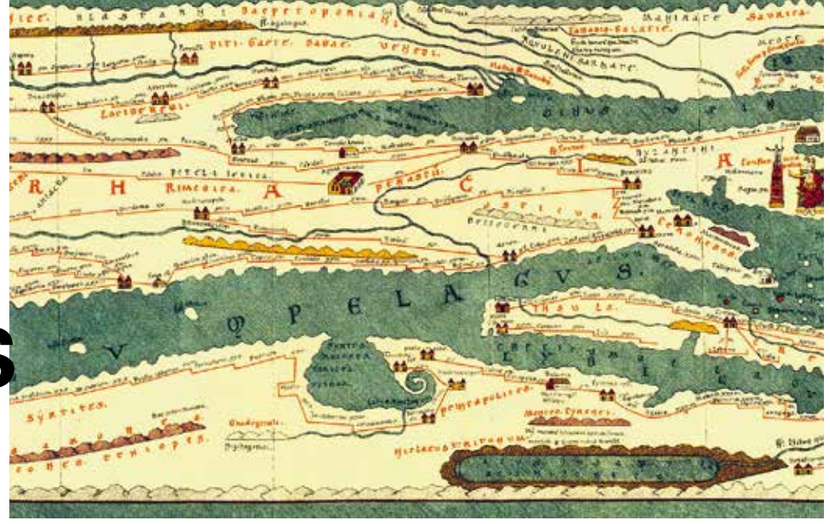
Photos: p. 16 University of Stuttgart, p. 17 Uli Regenscheit

Convenient and efficient: The autonomous campus scooters make their way to the waiting people independently. They can also optimize their distribution around the campus and drive to the charging point independently.

TRAVEL BROADENS THE MIND – AND DID SO EVEN IN ANTIQUITY



Top: Roman road network – the famous Tabula Peutingeriana

Bottom: Everyday life in Rome – on a Roman stone in Maria Saal, Austria

TEXT: Daniel Völpel

Mobility is not a new phenomenon. Even the travelers of antiquity, for example young Greeks who wished to study with famous scholars, had to travel vast distances.

As research carried out by the historian Christian Fron for his dissertation at the University of Stuttgart's Institute of History shows, travelling for the sake of gathering new impressions or to get an education in a foreign country was a privilege reserved for young men of the upper class in the Roman Empire. He focused his research on Greek scholars writing retrospectively about their travels at a young age.

"The mentality of travelers in antiquity was completely different to ours," Fron explains. Anyone wishing to travel from Germany to Athens today would usually fly. "The ancients knew they would be on the road for a long time. On a good day, it was possible to cover about 45 kilometers on average." So, wherever possible, people tried to enjoy the journey itself and scheduled many stops along the way. The reasons for journeys also differed to some extent to those of today. In addition to merchants, civil servants and soldiers travelling on business, one group in particular would go on their travels: young upper class men. For their career in the civil service, a career in which they would hold various offices, Fron explains, young Roman senators had to complete the *Cursus Honorum*, which often led them first to Africa, then to Gaul and Asia Minor in modern Turkey. Things were different for wealthy young Greeks, whose "Grand Tour of Antiquity", as the researcher calls it, was a journey to their chosen teacher. "They had the time and the means to travel abroad and pay their own way." →

→During the first to fourth centuries AD, conditions for these travelers were favorable. "One fundamental fact of the Roman imperial era was that a very large area was under a common ruler," as Fron explains. Roman coinage was accepted as legal tender from Gaul to North Africa, and from modern Spain to the Middle East. "Roman citizens, which increasingly included most members of the Greek upper class as of the second century AD, enjoyed the full protection of the law." A burgeoning economy made it possible to travel on board one of the many merchant ships, although this means of travel was unpopular, primarily because the status-conscious passengers were uncomfortable with having to subordinate themselves to a simple captain, eat simple food and because of the lack of privacy. Many felt the unfamiliar movements of the ship to be threatening, so, nearly all wealthy travelers would only travel by ship when speed was of the essence.

The preferred route was overland, but that also had its pitfalls: Ever present dangers included the cold, gangs of robbers and wild animals. Many roads were not passable in all seasons, which is why travelers usually set out in carts in the spring, to arrive in autumn at the latest. "Getting injured or falling sick on the journey could mean death on the road," says Fron: "Failing to return from a journey was nothing unusual." At best, the carts were sprung with leather straps on the axles. Passengers would be covered in dust and dirt after a day on the road, their bodies aching so much that they would have to take a day off at regular intervals. Traversing vast distances with such technical means was, according to Fron, a huge achievement. "I found records of journeys of more than 1000 kilometers as the crow flies."

GLOBALIZATION IN THE IMPERIAL ERA

These young men were driven by a sense of adventure, as travel was expensive, dangerous and difficult: having recently escaped their fathers' strict regimes for the first time, they wanted to have experiences and meet people. "Because they could prove useful at a later date, these Europe-wide contacts with other members of the upper class were maintained over a lifetime." says Fron: "I refer to this as imperial era globalization, and it brought the world closer together."

Because of the prevailing patriarchal structures, the writings of just a few female scholars have been handed down from antiquity. Essentially, as Fron explains, famous examples, such as Hypatia of Alexandria, were home educated by their fathers and rarely travelled. The patriarch would also generally have a decisive influence over what the son's career should be and where he could find the best teacher for this purpose. Athens, for example, was considered to be the non plus ultra for an education in public speaking. Occasionally, it is said, career planning was influenced by divine intervention: according to his later report, the father of the famous ancient physician Galen of Pergamon had seen Asclepius, the god of healing in a dream, who announced that his son should study medicine. And so began the search for an educational institution "that is good, useful and makes the neighbor envious," says Fron. So Galen studied in Alexandria, which was the center of medicine at that time.

Fron's most important sources were the scholars' own records. He also examined inscriptions and papyri such as that of a Theophane who travelled from Egypt to Antioch (today Antakya, Turkey) in the 4th century and kept exact records of what he bought and where. "One can obtain valuable information from these records about where he stopped for rest breaks, who accompanied him and the expenditure such a journey involved."

As the historian explains in summary, travel itself was the experience until the invention of the railway and journey time was not such a determining factor. In a letter from the Roman scholar Pliny, Fron discovered a parallel that is still valid today. Pliny describes having discovered an idyllic lake very close to his home, and stated that "we tend to travel and to cross the sea, to get to know things that, if we always have them right in front of our eyes, don't interest us." ↠

Roman myths – Achilles and Hector were a popular motif.

Photos: austria-forum.org/Werner Gobiet (2), p. 18 Ulrich Harsch Bibliotheca Augustana

USING THE MODULAR DESIGN PRINCIPLE FOR VIRUS DETECTION

Quick and easy: the demand for uncomplicated virus tests is high, and not only among travelers.

TEXT: Julia Hoscislawski

Low cost, easy-to-use mobile test procedures that can detect viruses, bacteria or environmental toxins could be useful in many areas. Jun. Prof. Michael Heymann and a team of students have developed a first prototype.

Life would be so much easier at present if it were possible to use a rapid test for the coronavirus that causes Covid-19, similar to a pregnancy test that could be used immediately upon first suspicion! This is a concept that, since the outbreak of the pandemic, has indeed led to a global research boom in detection methods. "Of course," says Michael Heymann, junior professor and head of the Department of Intelligent Biointegrative Systems at the Institute of Biomaterials and Biomolecular Systems (IBBS), "where pathogens were involved such as in the current case, biological safety – for example the the safe disposal of used test kits – would have to be taken into consideration and ensured."

Heymann probably never dreamed that the question of high testing capacities and fast detection methods could gain such traction in the public mind. His research focuses on biotechnological processes and the development of molecular programs, which, among other things, can be used in test procedures. He, as project leader, and 17 students first developed a low-cost fluorescence reader in 2017, which is the size of a small external hard disk and therefore fits in every trouser pocket. The results were published at the end of 2019.

The project team's main focus was on finding a simple way of distinguishing between viral and bacterial infections. "Too often," says Heymann explaining the idea of the virus detector, "doctors prescribe antibiotics for harmless infections on suspicion, which leads to antibiotic resistance, which has been increasing for years. Using a simple test procedure in their practices without the need for additional laboratory equipment, it might be possible to prevent doctors from prescribing antibiotics at all in the case of viral infections." →

→ The international Genetically Engineered Machine (iGem) competition, one of the most internationally renowned student competitions in the field of Synthetic Biology, in which the young researchers won second place in 2017, was the starting point of the research project. With their contribution, the students were able to demonstrate how a detector based on the CRISPR/Cas gene scissor mechanism is able to function with relatively simple modular components. In addition to integrating the molecular biological component, it also needed to be combined with hardware and software components.

POCKET LABORATORY

It is easy to see the enormous potential of rapid tests that use so-called decentralized approaches and not only in the context the current Covid-19 pandemic or the "pocket detector", which was developed further at the University of Stuttgart. "In future," says Heymann, "tests – whether for doctors or end users – could make dealing with viruses, bacteria and environmental toxins easier in many areas of life." He can think of a number of scenarios: they could be applications suitable for everyday use, such as a test that could be used to check the freshness of supermarket meat quickly and easily. There are also possible applications in the medical field: a smartphone extension linked to a microscope for the detection of skin cancer, for example, would be interesting. In the coming years, simple, compact test kits could also be of great help in telemedicine, in which digital diagnostic options would provide support for rural doctors in particular, who have a high workload.

These examples make one thing clear, which is that the question of how a laboratory could be miniaturized for portable use is just as relevant as the question of which new molecular biological components could be usefully used for detection. In this context, Heymann sees great potential in microfluidics, a field in which the behavior of liquids and gases in the smallest of spaces is studied. "Microfluidic systems technology," he explains, "involves the development and optimization of the manipulation of fluids in hair-thin channels in a manner similar or analogous to electrical engineering, which involves combining components and electrical currents at the smallest longitudinal scales. We are particularly interested in intelligent designs that can be operated simply and intuitively. To be able to carry a miniature laboratory in your pocket wherever you go would be great," he continues, "but, it should make life easier for everyone, not just experts; just as the mobile Internet does today."

In the smallest of spaces: Microfluidics involves the study of the behavior of liquids and gases.

ADDED VALUE FOR STUDENTS

However, until that time, there are still open questions to be explored in the field of biological programs and a certain amount of know-how still needs to be generated for the development of the associated biotechnological processes. It is possible that students will also be able to work on this in the future. Heymann and his colleague Prof. Peter Pott of the Institute of Medical Device Technology have just received approval from the University of Stuttgart for an open laboratory. Known as MEDtechBIO, it will be a fixed structure for extra-curricular projects within the newly established "School for Talents". The idea is that motivated technical biology and medical technology students will be able to pursue their own research questions there, which will give them an introduction to research at an early stage of their studies. "We want to promote the creativity and determination of the students in a very direct manner. Combining current scientific and experimental focal points from different disciplines is of particular importance to us, which is an approach that we find difficult to achieve in the context of traditional internship experiments." Heymann points out that the added value for the students will become directly tangible and includes positive new incentives for further studies as well as for their future careers. →|

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Photos: Unsplash

HIGH TIME FOR NEW VISIONS

GUEST ARTICLE: Theresia Bauer

There is a widespread consensus about the need for a traffic transition, but it breaks down when it comes to the question of how to achieve it. In the following guest article, Baden-Württemberg's Minister for Scientific Affairs, Theresia Bauer, reflects on ways to wean ourselves off the car, future-oriented mobility visions and the role of science.

The current reality of our lives is still dominated by mobility concepts from the past. Our current economic success and living comfort would certainly not have been conceivable without the visions of that period. We have become far more mobile and much greater social progress has been made possible. Think of the recognition that engineering has enjoyed based on the car as an export product, how car owners have been filled with pride, the feeling of freedom and independence associated with owning one's own car, and how the automotive industry and engineering science at universities have cross-pollinated one another in a spiral of innovation. The relevant innovations were and continue to be a product of the mobility concept of that era.

It is now high time to develop and implement new mobility concepts, because we want to build on past successes. The current social consensus about the fact that a change in transport policy is necessary to protect the climate is all but ubiquitous. However, when it comes to the question of how the entire transition is to be managed in such a way that it will have a concrete effect on our lives and ensure our prosperity, we are still have a→

Theresia Bauer

“We in Baden-Württemberg wish to continue being a driving force in mobility technologies”

Theresia Bauer, is Minister of Science, Research and the Arts in Baden-Württemberg and has been voted “Science Minister of the Year” by the members of the German Association of University Professors and Lecturers three times since taking office in 2011.

→long way to go. Change does not simply happen “top-down” in a democracy; it takes a social *tour de force* and requires the conviction and creativity of many.

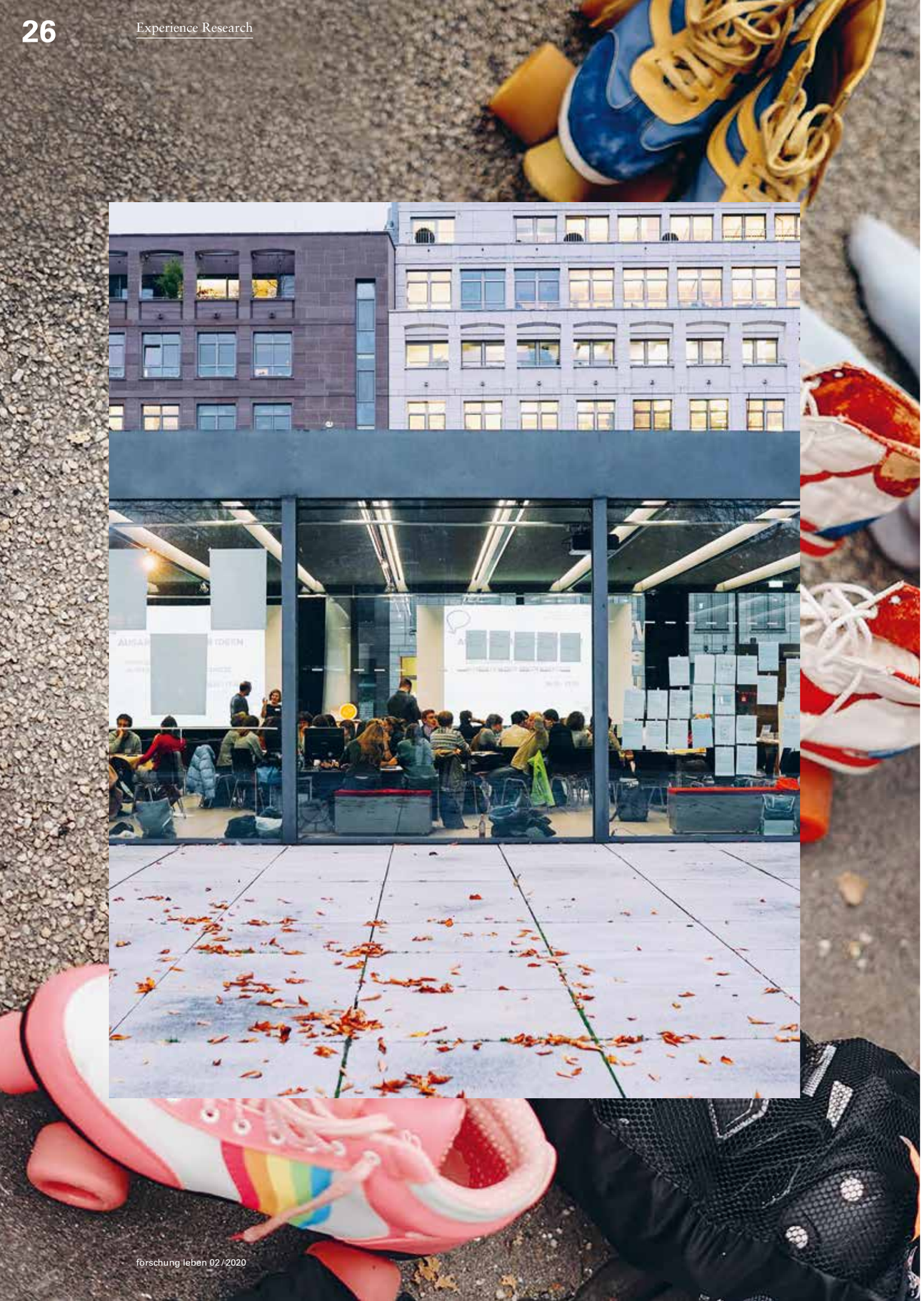
I view the universities and colleges as places capable of making an outstanding contribution towards shaping this change. They have the freedom to get to grips with mobility concepts and feasibility in a very fundamental manner and unfettered by any particular business model. Visible scenarios are needed to open up the range of possibilities for social discourse, and experts are required who can provide citizens with well-founded analyses. And, last but not least, enthusiasm for and openness to new approaches are essential if old ways are to be abandoned. The real labs format is going in precisely this direction. The campus as a laboratory of the future should make such experiential spaces possible. The University of Stuttgart, for example, has sought the active involvement of urban society with its “Real Laboratory for Sustainable Mobility Culture” and has provided material for discussion through actions. This exemplifies a science community that seeks dialog in shaping the future, which creates opportunities for discussion and moderates informed opinion-forming among the public. It keeps filling me with enthusiasm again and again. It inspired us in the Ministry of Science to go one step further: in our ideas competition for mobility concepts for the zero-emission campus, we gave eleven universities in the state of Baden-Württemberg the opportunity to develop a locally adapted, climate-compatible mobility concept in collaboration with their respective stakeholders. Until now, professional success, for scientists in particular, has been linked to above-average active mobility. If, in this context, it proves possible to develop transport-compatible alternatives, this could become a template for the lifestyles of others, so the needs of transport users were central in the competition. This is not a question of restricting mobility, but rather of ensuring that means of transport are climate-compatible whilst being user-centered and attractive at the same time. Both the researchers and students are part of the experiment. What the dynamics of the competition at the end of last year showed me was that universities can be appropriate drivers of change. It is possible to create new technologically and ecologically ambitious mobility behaviors with committed stakeholders, enthusiasm and energy. As the winner of the competition, the University of Stuttgart can now take the next steps towards implementing its mobility concept. Given the goal of achieving climate neutrality by 2035, an infrastructure-supported incentivization system and innovative modules that clearly demonstrate the university’s research achievements, MobiLab serves as our beacon for a sustainable mobility concept. The objective is to make tomorrow’s mobility tangible on campus.

OPTIMAL RESEARCH CONDITIONS

At the same time, we are investing in methodological and technological developments that are driving the transformation of Baden-Württemberg’s core industries. The University of Stuttgart and KIT are pooling their know-how in the fields of mobility and production in the “Mobility of the Future” innovation campus. We want to use this to provide young researchers with optimal research conditions for launching technologies which will have an impact on the transport system.

The Ministry of Science is shaping the research and innovation environment in the strategic dialog with the Baden-Württemberg automotive industry with two experimental fields: the Innovation Campus and mobility concepts. After all, we in Baden-Württemberg wish to continue being a driving force in mobility technologies in the future, which we will succeed in doing if the relevant technologies are embedded in practical concepts that meet the climate goals, and which simply generate enthusiasm thus keeping graduates and jobs in our state. Enthusiasm for the cause will advance and promote new technologies, awaken the entrepreneurial spirit and will also consolidate the state’s international reputation as a mobility hub. →|

Photo: Sabine Arndt



INTO THE CITY

TEXT: Jutta Witte

Real labs are taking science to society Among other things, the University of Stuttgart's Institute of Urban Planning and Design is committed to collaborative experimentation. Their "Real Laboratory for Sustainable Mobility Culture" has hit the nail on the head in a city famed for its car manufacturing.

“Stuttgart is on the move.” Students, teachers and the public got together in the workshop to present and discuss their ideas about mobility on an “ideas wall”.

As Martina Baum, Professor of Urban Planning and Design at the University of Stuttgart and coordinator of the “Real Laboratory for Sustainable Mobility Culture” explains, “we work with the public to conduct research into the issues that shape their lived realities and we learn together.” “Sustainable mobility culture”, which is what the lab’ is focused on, is an obvious choice in Baden-Württemberg’s capital city. Stuttgart is one of those typical German car-friendly cities developed on the drawing board in the 1970s. Even today it is still dominated by the car and the negative consequences have long since become abundantly clear: Congestion, noise and air pollution are putting a strain on the environment and reducing people’s quality of life.

For many years, mobility in this country has been considered to be synonymous with driving a car, and mobility concepts have been based on rewarding the use of one’s own private car. The stakeholders in the Real Laboratory have completely rejected this paradigm and wish to rethink mobility culture in a way that places people at the center of planning and design. “We’re not about restricting mobility,” Baum emphasizes: “But we do want to call the strong focus on the car into question and point out other possibilities.” Since 2014, seven of the University of Stuttgart’s Institutes have been collaborating with other universities and research centers, associations, institutions, municipal administrations and the public in the laboratory, which is funded by the state of Baden-Württemberg, in the search for concepts that conserve resources as well as promoting health and public participation.

CONSCIOUSLY EXPERIENCING INTERVENTIONS

During the first funding phase which ended in 2017, the researchers focused on making as many members of the public as possible aware of this highly contentious topic, whereby the focus has been on discussions, offers such as rickshaws or new places of encounter such as converted car parking spaces and the “Stäffele” staircases, which are typical of Stuttgart. The primary focus in Phase two was on experimenting in the public sphere. “What we learned from the first phase,” says Baum, “is that the best way to stimulate the discourse is through interventions in urban space that can be consciously experienced and lived.” →

→Three student projects which produced winning designs in Baum’s “Provisional Architecture” seminar demonstrate new forms of practical discourse on the topic of mobility and urban society. How do we get around in the city? Who owns the spaces that have mainly been occupied by cars up till now? These were the questions that interested Ali Hajinaghiyoun and Felix Haußmann in their “StadtRegal” experiment. For a period of six weeks, the multifunctional furniture was installed at Österreichischer Platz, which is a space dominated by a seemingly surrealistic traffic roundabout-bridge structure. The shelving provided space for emergency accommodation, a communal kitchen and a cargo bike rental outlet as well as flexible uses such as a food sharing, a medicine cabinet and space for communal cooking events. It developed into a space for spontaneous encounters for people from very different backgrounds.

ROLLER SKATING RINK FOR ALL

The second of the winning projects also quite literally revolved around Österreichischer Platz. “How do you roll?” was what Cristina Estanislao Molina and her colleagues wanted to know. The basic concept involved transforming the space which “actually doesn’t relate to people at all” into a public roller skating rink for two hours. Except for cars, it was open to any type of vehicles, from skateboards and bikes to rollators. Many people, especially families, responded to the call issued under the slogan “the city belongs to us all”. With music in the background and kids on roller skates, adults on cargo bikes and teenagers on unicycles, it was a very special experience for the 25-year-old Estanislao→

Martina Baum, Professor of Urban Planning and Design

“We’re not about restricting mobility. But we do want to call the strong focus on the car into question and point out other possibilities.”

Winning project “StadtRegal”: Students assemble the experimental furniture (above).

The multifunctional system has become a popular meeting place (left).

“How do you roll?” the winning project: Bobby cars ruled the streets for two hours ...

... Skateboards, extravagant bikes – in short: anything with wheels except cars, ...

... Österreichischer Platz – normally a traffic hotspot.

→Molina: “this just goes to show how much you can get done if you follow up a good idea with a passion.”

Christian Köhler and his team invited the people of Stuttgart to take an imaginary journey into the past and asked, as part of their “Stuttgarter Luftbahn” project, what form of mobility the pioneers and masterminds of the late 19th century had been betting on. This led to the idea of telling the history of the “Luftbahn” (aerial tramway), a hot air balloon equipped with a passenger gondola. They also posed the tongue-in-cheek question of whether the “aerial tramway” might experience a renaissance and transport people from station to station in crowded urban areas with no noise or emissions. The project team designed a route plan for their hypothetical public transport system and built a railway station in style of the era. “What we did,” says Köhler, “was, as it were, to develop a future of the past.”

EXPERIENCE-BASED KNOWLEDGE OUGHT TO BEAR FRUIT

All project teams produced temporary interventions in collaboration with their various partner institutions, which met with great interest. Even though the main project will officially end in August 2020, Martina Baum hopes that the experience gained over several years in the Real Laboratory will continue to have a tangible effect within the city. She now knows that: “the University of Stuttgart could make a major contribution towards mastering the huge challenges we face as a society”, which, for the urban planner, confirms that the transdisciplinary approach to which Real Labs are committed has been established successfully. ↠

Transdisciplinary: interdisciplinary researchers collaborate on an equal footing with stakeholders from the general public.

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Photos: p. 26 Lewin Biskupski, University of Stuttgart, p. 27 Ali Haji, p. 28 University of Stuttgart, BlattKunst, p. 29 Uli Regenscheit, Ali Haji, University of Stuttgart, p. 30 Lewin Biskupski, p. 31 University of Stuttgart

Winning project “Stuttgarter Luftbahn”: The project team took people back to the future.

The students even designed a route plan for the hot air balloon with its passenger gondola and passengers in period costume.

HANDLING CONFLICTS IN A DEMOCRATIC MANNER

TEXT: Jutta Witte

In this interview, Ali Hajinaghiyoun, one of the co-initiators of the "StadtRegal" project, talks about why a piece of furniture such as shelving can be exciting from an urban planning perspective.

Ali Hajinaghiyoun studied architecture at the University of Stuttgart.

Photo: Ali Hajinaghiyoun

Mr. Hajinaghiyoun, you were one of the co-initiators of the StadtRegal experiment: what made you choose this piece of furniture as a model?
Shelving divides a room into different spaces, thus lending it a certain order. It's the same in urban spaces. The question arises as to who decides how and for what these spaces should be used, particularly in regard to transformation processes. Who makes the rules? We want to contribute towards democratizing such conflicts.

What conflict situation did you find?
Our StadtRegal was located at Österreichischer Platz in Stuttgart, an area still dominated by cars, but which is currently undergoing a transformation. The urban population has→ made many attempts to use it in different ways, from an outdoor cinema to a flea market. The only group that has never been involved includes the homeless, drug addicts and alcoholics who live there under the bridge – a bit of a depressing observation.

Did you manage to get these people involved?
The general public has made intensive use of the StadtRegal. What this intervention showed us was that more people developed a sense of responsibility for this area and in a new way, and the mingling of various social groups. Although, of course, there were conflicts. Our greatest achievement was giving these people a voice at the level of urban policy-making.

You're currently living in Hamburg as a freelance architect and urban planner: can your concept also be applied to other cities?
We constructed the StadtRegal especially for Österreichischer Platz, but, of course, this design approach can be used in many different contexts, whenever spaces need to be transformed and used in novel ways.

What lessons have you taken from this experiment?
What I mainly realized is that we architects and urban planners have to redefine ourselves. Far from being mere service providers, we also need to consider the consequences of our interventions on people's social environment. →|

Prof. Thomas Graf of the IFSW adjusts the laser beam.

Mobility in the field of 3D printing

TEXT: Andrea Mayer-Grenu
PHOTOS: Max Kovalenko

Leap-frogging innovations and new technologies are set to make the car production state of Baden-Württemberg into a showcase of contemporary and sustainable mobility. To this end, the University of Stuttgart and the Karlsruhe Institute of Technology (KIT) have joined forces with the "Mobility of the Future" (ICM) innovation Campus.

"Essentially," says Dr. Max Hoßfeld, Managing Director of the ICM in Stuttgart, summing up the problems of today's mobility behavior, "we still drive the same kind of cars as Bertha Benz, a car pioneer who personally took the wheel on her first successful long-distance journey in a car from Mannheim to the center of her native town of Pforzheim." "Basically, no city planner wants that these days," says Hoßfeld. This is because, private transport, as we all know, takes up a lot of space and produces exhaust gases and noise pollution. Yet, getting on top of these problems is also an issue in a state whose key industries depend on people buying a new car every few years. →

High resolution and surface quality in stereo-lithographic printing

→But vehicle sales had started to falter even before and especially during the Covid-19 crisis, which has drastic consequences in terms of corporate profits and the labor market. “The conventional automotive industry business model will only last for another one or two vehicle generations at most,” says Hoßfeld, describing the challenges, “after which we will need different solutions.” What we need is a transformation of mobility culture and its related products and business models, but also of our current globally fragmented value chains. “We have to bring value creation back to Central Europe to reduce global dependencies, and, to achieve that, our production system has to become more flexible and efficient.”

It’s all about “advanced Manufacturing.” Researchers at the ICM are pursuing the vision of a universal production technology or “universal machine” to take this to a new level, which will combine currently separate serial production processes in a single system technology. Once set up, this flexible all-purpose system will be able to accept direct CAD data input and then produce practically any component on site as required, even if the batch size is 1. 3D printing, which can not only be used to produce high-quality (lightweight) components, but also components with novel integrated functions, will be a key technology in this context.

A LEADING ROLE FOR LASERS

“Most 3D manufacturing processes are laser-based,” explains Volkher Onuseit of the University of Stuttgart’s Institute of Laser Technologies (IFSW), which is involved in various ICM projects. This process involves melting metal wires or powder by laser to build up the workpiece and its contours layer by layer. The problem with this is that the surfaces of components produced in this way are relatively rough and insufficiently precise for accurate fitting with other components or to guarantee such properties as adhesion or friction, which means that they have to be reworked by removing part of the material prior to further processing. “This raises certain questions,” explains Onuseit: “how much more material do I have to build up to ensure that the post-processing process produces the desired result? How and with which tool can the part be produced? How could the processes be regulated?” Such questions can only be answered in an interdisciplinary manner. That’s why researchers from the fields of Automotive Engineering, Product Development, Production Engineering, Chemistry, Materials, Electrical Engineering, Aircraft Design and Machine Tools are collaborating in the ICM. The relevant topics are being dealt with by research teams from Stuttgart and Karlsruhe. “This works extraordinarily well,” says Hoßfeld, who is also responsible for the operational collaboration between the two locations: “the complementary competences in both basic research and technology transfer, for example, complement each other perfectly.”

A BETTER UNDERSTANDING OF INTERACTIONS

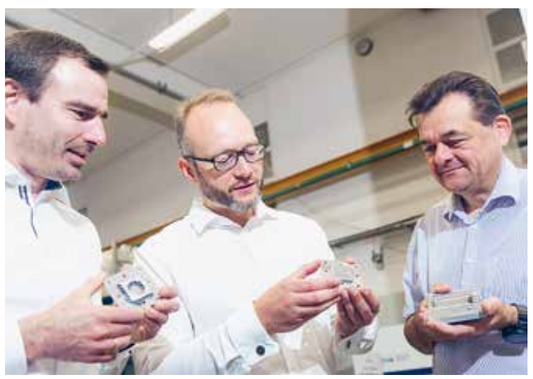
The University of Stuttgart’s Institute for Machine Tools (IfW), the IFSW, the Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW) and the Institute for Materials Testing, Materials Science and Strength of Materials (IMWF) are therefore collaborating in a pilot project to investigate final, contour-optimized production as well as the optimization of additively manufactured component properties. The KIT Institute of Production Science (wbk) is involved. One particular challenge in the optimization of the final contours is the interplay between 3D manufacturing and finishing. “Melting powder or metal influences the material properties within the component,” explains the Director of the IfW, Prof. Hans-Christian Möhring, “the residual stress for example.” Removing material during post-processing changes these conditions again. “We want to gain an understanding of this complex chain of effects and model the component properties.” →

Top: Dr. Dina Becker checks the accuracy of the shape of the cylindrical test component.

Right: Surfacing a 3D-printed test component

Left: Dr. Becker inspects a test component with his research assistant Steffen Boley.

Bottom: Prof. Hans-Christian Möhring, Dr. Max Hoßfeld and Prof. Thomas Graf

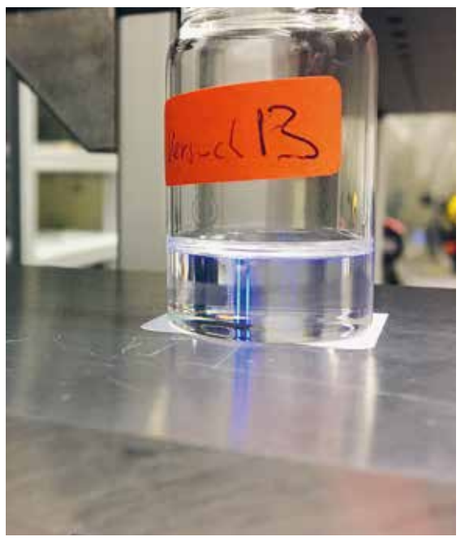


→As an initial step, Dr. Dina Becker, an academic employee at the IfW, has the IFSW produce small cylinders of aluminum wire using the laser cladding technique. Her goal is to discover how many lengths of wire must be laid out to achieve a certain material thickness, as well as how wide the melting band becomes and what effects this has on the component shape accuracy. "We have already been able to define a minimum wall thickness during our tests at the IFSW," she says, "but, initially, the accuracy and surface quality of the cylinders were not optimal. We need a homogeneous wall thickness." So, in the next step, Becker varies the post-processing parameters and analyzes how these affect the material properties. The research being carried out on comparatively simple components, such as cylinders, will later be applied to complex component geometries. "Our objective," Möhring explains, "is to understand the entire process of additive-subtractive (3D) manufacturing such that we will be able to adjust individual processes even for complex components and achieve certain properties in a conscious manner."

OPTIMIZING 3D PRINTING

However, additive manufacturing (3D printing) has one disadvantage – it is slow and expensive. The objective of another project, in collaboration with the Institute of Aircraft Design (IFB), the Institute of Polymer Chemistry (IPOC), the IFSW and the Karlsruhe-based wbk, is, therefore, to increase productivity, whereby the speed of production is one of the key variables. "We want to use ultrashort pulsed laser beams to increase the production of high-precision components in resin-based additive manufacturing processes from the current few cubic millimeters per second to cubic centimeters per second to achieve relevant production volumes for future mobility applications," explains Tristan Schlotthauer, a research associate at IFB. The researchers are investigating how dynamic laser beam shaping based on two-photon polymerization could be used to decouple the production process from the layered production that has been used to date.

A second variable would be not only to print individual components, but complete assemblies which would dispense with subsequent assembly tasks. Various things , such as metallic inserts for particularly stressed areas or mechatronic components that perform sensor and actuator functions can also be integrated into the components during printing.→



Left: Blue light caused by the two-photon polymerization effect in the resin basin at the Institute for Aircraft Design.

Right: Good shape, thin walls – the surface quality can be improved at the IfW.

Prof. Nejila Parspour is using 3D-printed soft magnets.

"Our research makes new types of motors possible, from which we expect much higher levels of efficiency."

→"This has not been possible until now, or was only possible at great expense," says Volkher Onuseit of the IFSW.

UNIMAGINED DEGREES OF FREEDOM

This can also result in the creation of new component types that give designers in the mobility sector unimagined degrees of freedom, which Prof. Nejila Parspour of the Institute for Electrical Energy Conversion (IEW) believes will be of particular benefit in the field of electric mobility. Together with the IFSW and the Karlsruhe Institutes for Product Development (IPEK) and for Vehicle System Technology (FAST), the IEW is searching for ways to better solve one of the basic problems of electromobility using 3D-printed components: "Electric motors", she explains, "have to be lightweight and compact whilst also achieving extremely high levels of efficiency in urban traffic and on the freeway, i.e., in very different speed ranges." A magnetic field, which converts electricity into speed plays a key role in this. There are three influencing variables that can optimize this conversion process, which include the design, which consists of mathematical algorithms, the controller and the "ingredients", such as hard and soft magnets.

Parspour and her team came across chemists at Aalen University who produced such magnets using 3D printing almost by chance and were inspired, and not only because magnets can be produced in large quantities and with special structures using 3D printing. "The real breakthrough," she explains, "is that, similar to knitting, 3D printing enables each layer to be designed differently." "One can integrate air or other materials into the soft magnet layers," which is exciting because the magnetic field always follows the path of least resistance and is attracted to areas of good conductance whilst avoiding air pockets. Therefore it is possible to integrate areas with different levels of conductivity in soft magnets to channel the magnetic flux in the desired direction, which "makes new types of motors possible, from which we expect much higher levels of efficiency," as Parspour says with enthusiasm.

But 3D printing can also be used to produce solid magnets in a more differentiated manner. To stabilize their thermal behavior, these contain rare earth elements, which are currently expensive and are also often extracted under questionable conditions. "3D printing," Parspour explains, "enables us to incorporate rare earth elements into components in a very targeted manner, i.e., depositing more in areas that get warm and less elsewhere." This will not only benefit future mobility but also the general conservation of the environment. ↠

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MOBILITY

SNAPSHOT IN FIGURES

Data and facts can, and ought to, provide an important basis for decision-making, not least in transportation and environmental policy, yet they can also increase individual knowledge and perhaps even stimulate people to reflect on their own behavior: Some may be horrified by the number of cars registered in Germany or by the time lost in traffic jams. Yet, at the same time, the fact that three out of four households own a bicycle may give them a new sense of community.

46 hours Germany

115 hours Great Britain

99 hours USA

This is the average length of time drivers spend in traffic jams every year.

Source: Inrix 2019 Global Traffic Scorecard

About 25,000 car-sharing cars

were approved in Germany in early 2020. A tiny fraction of the **approximately 47 million cars**.

Source: ADAC, Carsharing-Statistik 2020

76 % of all households

in Germany have at least one bicycle. **14% of households** own a pedelec.

Source: BMVI, Fahrrad-Monitor 2019

60.7 % is the proportion of CO_2 emissions from cars within the transport sector. For comparison: rail transport accounts for just **0.5%** .

Source: European Environment Agency (2016)

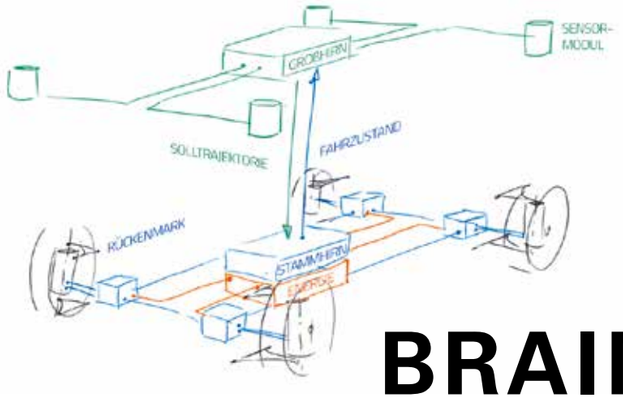
3.1 trips and 85 minutes per day

This is the average number of trips made and time spent travelling per person in Germany in 2017

Source: BMVI, Mobilität in Deutschland, Kurzreport 2019

138 times on average every German inhabitant took a bus or train in 2017. the trend in the use of public transport rose.

Source: VDV (2019)



Transfer service: the brain structure is applied to the vehicle in the UNICARagil project.

THE BRAIN AS A MODEL

TEXT: Jutta Witte

Driverless and automated e-vehicles, whose components function like IT service modules and which adapt to their environment in an agile manner: the UNICARagil research association is taking a completely new approach to automotive development.

The objective of the UNICARagil project is nothing short of rethinking the architecture of automated vehicles. "We take the IT industry as our blueprint and define each of our modular system components as a service that can be swapped out in a flexible manner, but still functions reliably regardless of the state of the overall system," explains Dr. Dan Keilhoff, coordinator of the project at the University of Stuttgart's Institute of Automotive Engineering (IFS). Ultimately, every type of assembly has to function without failing for the fully automated e-vehicle to be able to perform its driving services in a safe manner and without limitations at any time. This presents the approximately 100 experts from eight German universities and industry who have joined forces in the consortium with a complex challenge. The mechatronics engineers at IFS ensure that all components, from the control units and environment sensors to the dynamic modules that can be powered on and braked individually, are able to communicate among themselves. They also ensure the energy supply as well as the interior air-conditioning and the component cooling.

DOUBLE SAFEGUARDS

The human brain in combination with the central nervous system, says Keilhoff, provides "a good model" for the development of mechatronic architecture. The brain, for example, receives information from the sensory organs then processes it in specific areas before sending impulses to the muscles for the further conversion into actual actions. If one area fails, another can maintain vital functions. If there is very little time for decision-making – for example in stressful situations – the spinal cord rather than the brain is called upon and reflexes then make for fast reactions. "We're applying these capabilities to the new vehicle concept," explains the expert for automated and networked driving. →

→ The communication system primarily uses the local Ethernet data network. The "cerebrum" control unit is connected to four sensor modules, each of which monitors a part of the vehicle's environment. This creates various partial models, which the cerebrum combines to form an overall model, on the basis of which it calculates the so-called target trajectory, i.e., the route that the vehicle should take in the next few seconds. It then transmits this target trajectory, as well as an emergency trajectory, which defines an emergency safe stopping route, to the "brain stem" as the second control unit. This calculates how the four dynamic modules need to be controlled to keep the vehicle on the specified route, or, alternatively, on the emergency route. If, however, the brain stem sends implausible information about, for example, steering angle or torque, or even if it fails completely, the individual modules are able to communicate independently among themselves or directly with the cerebrum, just as the human spinal cord does.

Such redundancies, i.e., double safeguards, are vital for survival in the absence of a driver who can react instinctively and correctly in emergency situations, because the brain stem takes on a number of central functions in this system just as it does in humans. In addition to calculating the trajectory, it also performs a number of other functions, including the vehicle's self-perception system, which continuously records its current status and forwards this information on to the cerebrum to update the driving plan.

HARDWARE FOR THE BRAIN STEM

The research team has developed fail-safe hardware for the brain stem that can be expanded to cater to different application scenarios and a power supply system that is divided into four zones in line with the overall design of the new electric vehicle: these can be connected to each other, but can also be operated in an isolated and independent manner should one of them develop a fault. Safety-critical components are connected to two on-board networks. At a later date it will be possible to charge the four batteries wirelessly and automatically via induction. The plan is to feed the thermal on-board network mainly from the excess heat generated, for example, by the drive units, batteries and control units, so as not to overly restrict the vehicle's range.

"We want to show what is technically possible in the development of new mobility concepts," says Dan Keilhoff and emphasizes the fact that: "The automotive industry will have to reinvent itself to a certain extent." Halfway through the UNICARagil project, which started in 2018, his team has installed the complete mechatronic architecture in the first prototype of the vehicle chassis. The goal is to have four versions of the highly automated e-vehicle – a taxi, a private car, a minibus and a van – which are able to operate on chassis of different lengths by the end of the project in early 2022. ⇥

Teamwork: the IFS experts depicted here are members of a consortium consisting of about 100 people.

Mechatronics:

The field of mechatronics combines mechanics and-technical engineering with electronics and electrical engineering as well as computer science and information technology.

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Photos: p. 42 RWTH Aachen University/ika, p. 43 Universität Stuttgart/IFS

Differentiated: muscle tension, for example, can be measured in the driving simulator.

FLEXING MUSCLE IN CRASH TESTS

For teaching and research: the driving simulator was developed at the ITM.

TEXT: Michael Vogel
PHOTOS: Uli Regenscheit

Accident safety simulations include an inadequate representation of one critical factor: the human being. This situation could be changed with improved digital human models.

A crash test is an impressive experience: whenever a vehicle crashes into the wall, it shakes up the sensor-laden dummies inside the vehicle pretty severely. For a long time now, tests such as these have not only been performed in real life, but also in computer simulations, which include virtual dummies. Crashes involving vehicles made up of bits and bytes save a lot of time and money, but whilst the vehicles modelled in these simulations are replicated in an extremely realistic manner, the virtual dummies are still what they already are in real-life crash tests – incomplete approximations of the human body. What this means is that, although the weight, dimensions and rigidity of the individual body parts correspond to those of the average population, they do not come close to the complexity of the human locomotor system – neither in real-life nor in virtual tests or, to put it bluntly dummies don't have muscles.

"This means that vehicles cannot be developed in a human-centered way," says Prof. Syn Schmitt, head of the Institute for Modelling and Simulation of Biomechanical Systems and researcher at the University of Stuttgart's "Stuttgart Center for Simulation Science" (SimTech) cluster of excellence. Yet there are three good reasons for placing humans at the center of vehicle development: first, future safety systems should provide even better protection for vehicle occupants, particularly during the immediate pre-collision phase →

Not a question of posture: the digital human model can simulate anything.

→and with regard to non-life-threatening injuries. A person's actual stature plays a decisive role, for example, because it makes a difference if the person involved is a lightweight of 50 kilograms or weighs 150 kilograms. Second, these occupants will no longer necessarily occupy the classic seating positions when emergency braking occurs in autonomous vehicles; they might be dozing with thebacks of their seats folded back or be sitting with their backs to the direction of travel. Third, any such autonomous car must be able to detect whether a pedestrian is about to cross the road abruptly. Currently, this person is perceived by the on-board systems as little more than a silhouette from which the intended movement is difficult to derive.

CONVERGING ON REAL-LIFE MOVEMENTS

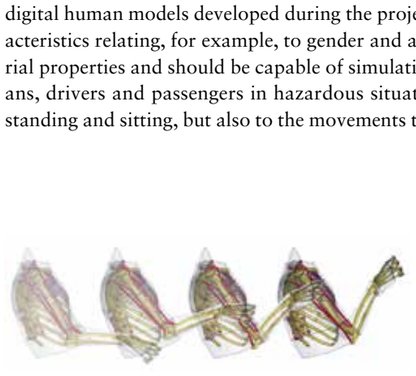
As the results of real crash tests published by the ADAC this spring, for example make clear, none of this is purely theoretical. According to these results, today's three-point seatbelts offer no protection to passengers in rear-facing or recumbent positions; sitting sideways can also result in injuries, even from the seatbelt itself.

"We need better digital human models to assess the risks that will be involved in future driving situations," says Schmitt. "Better", in this context, means human models that not only includes bones and the correct mass distribution, but also muscles and tendons, because these are the main factors that determine posture and movement. Schmitt and his team are developing such human models. Like all simulation models, a human model is basically a set of mathematical equations, which in this case describe interactions within the musculoskeletal system. Human beings have 656 muscle-tendon units of which Schmitt's most complex model takes account of 580, "all except those in the face, fingers and hands". Such human models are not only of interest to the automotive industry, but also for such fields as medicine and medical technology.

"Our human model is stored in a database," Schmitt explains. "To answer specific questions," he continues, "we often use just that part of the model that is particularly relevant to the movement under investigation, which may be an arm or the legs." Human movement "results from the interplay between the brain and nervous system with muscles and the musculoskeletal system. It is not possible, at present, to depict this interaction in the digital human model on a one-to-one basis, because it is far too complex and not yet fully understood, which is why Schmitt's team is developing mathematical descriptions that reflect the real movements as closely as possible.

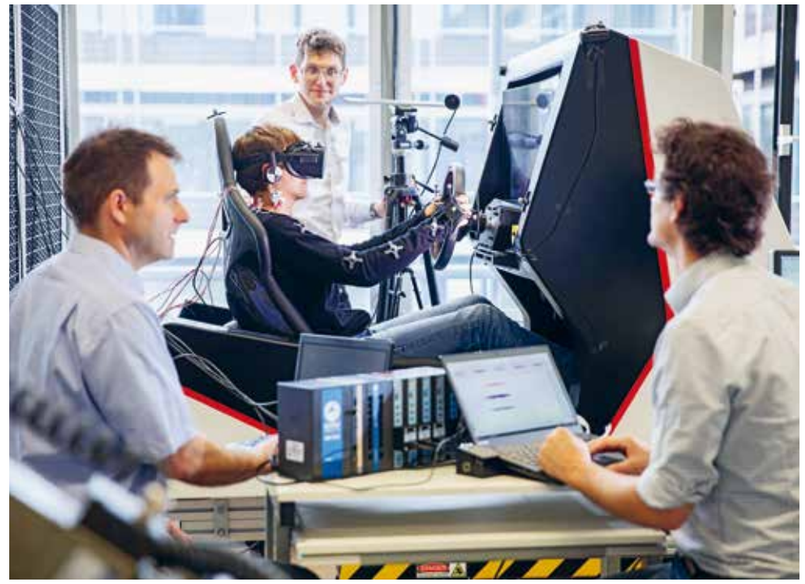
The team is creating the basis for integrating such digital human models into future crash simulation systems within the framework of the EU's OSCCAR project, among others. The 3-year OSCCAR project which has a budget of just under 7.7 million euro, involves some 20 partners from industry and the research community, including Bosch, Daimler, Siemens, Toyota, Volkswagen and Volvo, and is due to end in June 2021. The digital human models developed during the project are to take into account specific characteristics relating, for example, to gender and age and will incorporate improved material properties and should be capable of simulating the muscular movements of pedestrians, drivers and passengers in hazardous situations. "This applies to such postures as standing and sitting, but also to the movements that occur during braking, steering and→

Individual body parts as well as the whole human being can be represented.



Right: Prof. Jörg Fehr (at the back) is a member of the team that is researching methods for the validation of human models.

Bottom: Prof. Syn Schmitt designs human models that incorporate hundreds of muscle-tendon units.



Prof. Syn Schmitt

"We need better digital human models to assess the risks that will be involved in future driving situations."

→swerving," says Schmitt. "Commercially available human models still can't do that and are practically static."

VALIDATION IS ESSENTIAL

In addition to developing the digital human models, it will be essential to validate them to represent the thing as accurately as possible, which is done, for example, using real data from experiments with volunteers. This is where Prof. Jörg Fehr, Deputy Director of the University of Stuttgart's Institute of Engineering and Computational Mechanics (ITM) comes in; like Schmitt, he is also a researcher at the SimTech Cluster of Excellence. During his doctoral studies, Fehr had a driving simulator with an appropriate mensuration sequence developed and set up at the ITM. "There are much more powerful driving simulators, even at our university," says Fehr, "but our simulator can demonstrate ways of validating digital human models in a very cost-effective manner. This also enables us to introduce students to complex scientific issues." To carry out the tests, his team collaborates with Prof. Tobias Siebert and Privatdozent Norman Stutzig of the Institute of Sports Science and Kinesiology (INSPO). One of the central themes of their research is the further development of muscle models to better represent muscle forces in highly dynamic accident→

Prof. Jörg Fehr

“Our simulator can demonstrate ways of validating digital human models in a very cost-effective manner.”

→situations. “The INSPO team measures the muscle tension in the test subjects within the driving simulator, whereas we expose them to various traffic situations and analyze their movements,” explains Fehr.

TOWARDS MORE INDIVIDUAL PROTECTION

One relevant question in this context is what changes take place in test subjects’ musculoskeletal system, when forced to brake abruptly? It is well known that people who see a collision coming, reflexively tense their muscles to protect their bodies, a fact which has not yet been taken into account in virtual crash simulations, and especially not the fact that a well-trained 20-year-old might protect his or herself better than a feeble 80-year-old. “Our current safety systems only protect the average passenger, not the individual, whose stature, musculature and reactional behavior are specific and particular,” says Fehr. The varied behaviors of real people can be studied in the simulator and then integrated into the digital human models.

The following step involves extensive testing with several dozen volunteers in the simulator. “The digital human models provide numerous parameters and thus different ways to describe movements,” says Fehr, explaining the basic problem that he hopes to solve through validation. It is often unclear how exactly muscles are controlled, because the control path is often non-linear, and basically involve tiny control signals that trigger major changes, but which cannot be identified in a causally isolated manner as part of the movement as a whole. So, to some extent, the emergence of the movement remains misunderstood. But more importantly, one cannot play through all conceivable scenarios, because there are simply too many. “On the other hand,” says Fehr, “the real data from the driving simulator helps us to narrow down the parameters for describing motion in the human model.”

Schmitt and his team also attempt to do this in other ways. One new approach, the essential feasibility of which they recently demonstrated, is based on artificial intelligence (AI). “We no longer need to understand the exact cause of movement in a given muscle group, but simply use machine learning to recognize patterns,” said Schmitt. In the digital model of the arm, for example, an algorithm could run through all the movement control parameters and would then receive feedback on whether its result is correct or not, and would gradually learn which values to assign to the parameters. According to Schmitt’s vision: “it will be possible at some point to integrate complex motion sequences into simulations that the digital human models would have previously learned themselves,” at which point AI and digital muscles would simulate real movements with near perfection. ↠

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Photos: University of Stuttgart/SimTech

TRUCKER'S ASSISTANTS

The project team visits the TANGO truck during the mid-term presentation

TEXT: Michael Vogel

Highly automated trucks require user-centered technology. A research project in which the University of Stuttgart was involved provided relevant recommendations.

It is not only cars that are being equipped with an increasing number of driver assistance systems, but also trucks. Emergency braking assistants, distance and speed controls, lane departure and fatigue warnings are all virtually standard in today's trucks, and improve road safety by supporting the drivers. However, they do not relieve them of their responsibility: drivers must be in full control at all times. Yet advances in truck automation will continue, with man and machine forming a team and taking turns at driving, a process that absolutely has to go without a hitch. "It takes two to tango", as the old saying goes, and TANGO (Technology for the User-Friendly Optimization of Automated Driving) is the name of a project in which companies and universities collaborated to develop a driver assistance system for trucks that enables drivers to experience automation as a tangible added value.

"Once a driver has handed over control to the system, he or she still has to be able to quickly take back control if the machine gets overtaxed," explains Paula Laßmann, who is completing her doctoral studies at the University of Stuttgart's Institute for Engineering Design and Industrial Design. "This is why," she continues, "we developed a prototype for an attention and activity assistant (AAA) in the course of this project." This monitors the degree of driver distraction with a view to getting him or her to refocus on the driving task in hand in good time, as this is not something that happens in a split second. Tests have shown that this can easily take up to 15 seconds if, for example, the driver has been watching a video beforehand.

AT THE HUMAN-MACHINE INTERFACE

The TANGO project, which was funded by the German Federal Ministry of Economics for three and a half years, and involved the University of Stuttgart and Stuttgart Media University as well as Robert Bosch, MAN Truck & Bus SE, Volkswagen, CanControls and Spiegel Institut in Mannheim is due to end in September 2020. The IKTD's task was to design the AAA in such a way that drivers would find it useful. "There is a lot of research → into truck automation technology as such being carried out around the world, but little on the concrete design of the human-machine interface," says Laßmann. "So the TANGO project serves as a pilot." Many drivers have already switched off their assistance systems because, in their view, they are unreliable.

The AAA concept is based on three displays and several signaling devices within the cockpit. As is already the case, the instrument panel provides all information of direct importance for driving, such as speed. A second display, which is also already very common today, is used for navigation, load checking and for operating the music system. The third AAA display shows visual tasks which the driver can only work on after having had sufficient time to resume the driving task. An LED bar below the windscreen and several illuminated buttons on the steering wheel provide a visual indication of the current status and any pending need to retake control of the driving task. The latter is also supported by acoustic announcements. The AAA uses cameras to determine the driver's line of vision as well as the position and movements of his or her extremities, from which the system deduces whether he or she is tired or distracted.

NOT TOO MUCH DISTRACTION

"An essential part of the project involved studies with truck drivers," says Laßmann. These included both surveys regarding current assistance systems and observational studies conducted during real-time driving. "We conducted two studies at the IKTD involving drivers in a simulator," she explains. The test subjects were given other tasks to work on in addition to driving, one of which resulted in a cognitive and audio distraction, whilst the other distracted them in a cognitive and visual manner. The drivers had assistance systems at their disposal, which – as is customary today – they were required to monitor. "As expected, it appears that visual monitoring is only guaranteed when carrying out the secondary auditory activity," says Laßmann. The AAA was then integrated into the simulator during the second study to investigate how the transfer of the driving task between man and machine works at different degrees of automation. It was found that "the degree of automation must always be communicated very clearly to the driver," says Laßmann.

Based on all of the research results, the project participants have now derived recommendations on how the human-machine interface in automated trucks could be designed in an ergonomic manner. "In future, developers will understand which things seem clear and unambiguous to drivers and which do not," explains Laßmann. The project participants also made recommendations about acceptable degrees of distraction at various levels of automation. Safely watching a video, for example, would require a highly automated driving function that has not yet been approved for use on public roads. →|

Drivers can use tablets at automation level SAE L3.

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Photos: University of Stuttgart / IKTD

15 sec

The time taken by a driver to retake control

PRECISE TRACKING FOR TACKLING WRONG-WAY DRIVERS

TEXT: Judith Reker

Where am I? This question is not so easy to answer in a moving car; however, high-precision positioning is crucial for increased road safety.

Real-time alert: an app that warns of the presence on the road of wrong-way drivers is currently being developed.

Among the top ten scariest scenarios for drivers is probably the idea of a wrong-way driver approaching at high speed on the freeway. There are over 1800 such incidents in Germany every year. “What many people don’t know, however,” explains Prof. Volker Schwieger, head of the University of Stuttgart’s Institute of Engineering Geodesy (IIGS): “is that most wrong-way driver drivers don’t accidentally end up in the wrong lane; they want to kill themselves and take other people with them.”

So in the search for technical solutions it is not enough just to warn those who are driving in the wrong direction. “That would only encourage them in their actions,” says Schwieger. This is why the scope of the Ghosthunter project is much broader, starting with the detection of wrong-way drivers, and ending with a warning call that is broadcast to all nearby motorists as well as to emergency responders such as police and ambulances.

The IIGS, the Bundeswehr University Munich’s Institut für Raumfahrttechnik und Weltraumnutzung and NavCert GmbH have joined forces to develop such a system. The project, which began in 2015 is due to end in 2021 and is funded by the German Federal Ministry of Economics and Technology. The basic idea is that Ghosthunter will use the Global Navigation Satellite System (GNSS) to detect vehicles moving in an unauthorized direction. GNSS is a collective term applied to various satellite systems, such as the US-American GPS or the Eu-operated Galileo system.

One of the challenges is to match a vehicle’s current position down to the lane using data from digital road maps. The IIGS team, which is headed by Dr. Martin Metzner, is responsible for this so-called map matching function. Researchers can identify the vehicle position more precisely than before based on a map created specifically for this purpose, which includes individual road lanes. To this end, PhD student Philipp Luz developed a map-matching algorithm that incorporates a vast amount of data, such as lane markings, that has hardly been used before. More data results in a multiplication of potential mappings, yet the computing time must still remain below one second, because the warning needs to be issued in real time, ideally as soon as the wrong-way driver takes the wrong slip road onto the freeway.

DEFENSE AGAINST TERRORIST ATTACKS

“The IIGS has been conducting research into map matching for about 20 years,” says Schwieger, “in addition to digital road maps, modeling, data fusion and positioning.” They are also contributing this know-how to a project that deals with an even more worrying security scenario: truck-based terrorist attacks. Trucks as lethal weapons – the 2016 terrorist attacks in Berlin and Nice demonstrated this scenario. The “TransSec – Automated Prevention of Terrorist Attacks by Trucks” research network, which is funded under the EU’s Horizon 2020 program, has been working on a defense system against this danger since 2018.

The basic idea is similar to that of the Ghosthunter project and involves detecting prohibited maneuvers in real time. However, unlike Ghosthunter, the end result is the automated intervention into the driver’s braking system and halting the truck in its tracks.

The IIGS’s responsibilities include digital mapping, positioning and map matching. “If we want to detect someone turning off the road and onto the sidewalk in real time,” says Schwieger, “we need to be much more accurate than the usual GPS systems used in cars.” The researchers want to achieve this by using satellites and other sensors for more precise coordinate determination. Another objective is to develop additional sensors that would also detect objects, such as pedestrians, in the vicinity of the truck. The team adds them to static map objects such as roads or bridges as dynamic objects, which produces a Local Dynamic Map, which forms the basis for the permanent risk analysis of the moving trucks. ⇥

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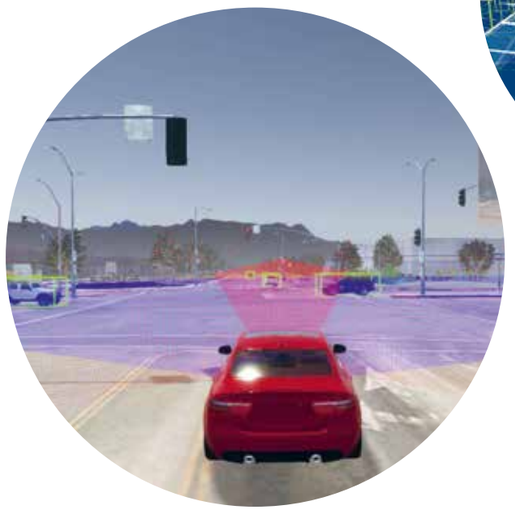
Illustration: Shutterstock, Axtesys GmbH

Like an experienced driving examiner



Artificial intelligence in the frame: software, such as the LGSVL simulator, helps to represent even extreme autonomous driving situations.

INTERVIEW: Jens Eber

Prof. Michael Weyrich and his team are working on new validation procedures to increase the safety of autonomous vehicles. Weyrich heads up the Institute of Industrial Automation and Software Engineering (IAS) and is dean of studies for the new "Autonomous Systems" course.

Professor Weyrich, autonomous driving systems will increasingly become a feature of road traffic: how great is current mistrust in this technology?
The extent to which people entrust themselves to this technology is actually rather amazing. There is already a high number of cars that drive automatically or even autonomously in the USA, and there are no fears whatsoever, although some challenging experiments are being attempted there. The industrial sector in this country is more cautious and is only introducing autonomous systems gradually, so we're not seeing much major distrust in the relevant technology. Just consider other autonomous aids within the private sector, such as voice-assisted automation in the home, to which people entrust themselves unreservedly.

Would you personally advise caution?
An autonomous driving system would have to cover a distance in the three-digit million range before it could drive as well as a human being with a degree of probability bordering on certainty. However, some American and Chinese manufacturers transfer automatic updates to the autonomous driving system at very frequent intervals and there's no way that they could have tested it as thoroughly as they should have. This is fundamental, because this is about life and death, as accident data shows.

Your institute has been working on validating autonomous systems for many years. How does this work in relation to autonomous cars?
On the one hand, we work with extremely elaborate real scenarios. Obtaining real test data is always very difficult, because we have to start large field trials to do so, which is→ why we mainly use simulations. We have a driving and robotics simulator in which we can also represent extreme situations.

What would be an example of such a critical situation?
Using neuronal networks in particular leads to completely new error patterns that would not happen to people in the same way. Take a car parked at the side of the road at an angle and with its rear end slightly in the roadway for instance: a human being would immediately see that someone has parked badly. But, the algorithm might see it as a car reversing out and make a dangerous and unnecessary emergency stop. Conversely, we define borderline scenarios by intelligently superimposing scenarios, which also need to be tested every time we update the software, which might involve, for example, a person in dark clothing in the dark or rain.

What is the exact objective of the validation procedures you're working on?
We're trying to make these tests effective, transparent and efficient, for example, by specializing in so-called corner cases, i.e., not just driving straight ahead on a country road, but instead looking for critical cases that rarely occur under normal operating conditions, like a driving examiner would do, who would deliberately put the test candidate in certain specific situations rather than simply letting them drive around. Our work involves the use of risk-based procedures to generate such exceptional situations. We want to discover where errors can occur as quickly as possible whether constructively or analytically. We try to think and act like an experienced driving examiner. By the way, this approach not only works for highly automated cars, but also for medical or production robots.

What tools do you use for this?
Modelling and simulation, with which we are extremely familiar here at the Institute of Industrial Automation and Software Engineering, play a key role, but you also require an evaluation algorithm which can select and specify the relevant test cases like the driving examiner I referred to earlier. This saves time, because one doesn't simply have to doggedly go through the simulation. We used an AI algorithm for this, which, like the driving examiner, decides which test case to generate next based on the observed behavior.

Is it realistic to expect no more claims for injuries or property damage in the long term?
This is more a question of social acceptance: as a society, we accept injuries and deaths in today's traffic, because we want to be mobile. The use of technology reduces known risks and creates new ones, but one has to make a conscious decision rather than simply giving the public something it ultimately doesn't even want at all.

What is the current status of your research?
We have a number of completed dissertations in addition to several publications and patent applications for these processes and we're in the process of acquiring further research projects, but we also have a spin-off called robo-test. I and my Institute colleagues Prof. Christof Ebert and Benjamin Lindemann as well as some students have set up a spin-off company based on these technologies. Our proud claim at the IAS is that we not only carry out research, but also put the results into practice, which attracts many students and companies: we live and teach the things we research. That's our motto. ⇥

Modeling and simulation: Prof. Michael Weyrich and his team are working on transparent tests for autonomous vehicles.

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Photos: p. 54 University of Stuttgart/IAS, p. 55 Sven Cichowicz

BROADBAND FROM SPACE

TEXT: Michael Vogel

Mobility and logistics of the future will require high data rates. To this end, a satellite project at the University of Stuttgart is opening up a new frequency band.

It's crowded up there: over 2000 functioning satellites are currently orbiting the earth. And it's getting even more crowded: certain companies want to launch tens of thousands of new satellites over the coming years. The space flight company SpaceX, which is headed by Tesla boss Elon Musk, is planning to offer broadband Internet services via over 1500 satellites by 2022. "Satellites already form part of the global Internet infrastructure," explains Sabine Klinkner, a professor at the University of Stuttgart's Institute of Space Systems (IRS). "On the one hand, they form the backbone of intercontinental data transmission together with submarine cables, and on the other, they provide alternative broadband access to the Internet to users in regions with poor telecommunications infrastructures."

The fact that companies, such as SpaceX, now wish to launch numerous additional satellites, is directly related to the ongoing digitalization in many areas of life. "Autonomous driving or the logistical monitoring of the flow of goods around the world will generate large amounts of sensor and navigational data, which needs to be made available to users without delay via the Internet ," says Klinkner. "But, the frequency bands currently available for satellite-based data transfers are already quite busy." So not only is it crowded in the near Earth orbital zone, but also for data transfers between satellites and ground stations. To ensure that data will not only be available in the fiber-optic and the new 5G mobile networks in future, the radio links to the satellites in question will also need to be exploited more effectively. "To do this, we have to open up new frequency bands," says the space flight engineer. She and her team are conducting research into this in the EIVE (Exploratory In-Orbit Verification of an E/W-Band Satellite Communication Link) project, which was launched in 2019.

DETECTION UNDER SPACE CONDITIONS

The EIVE project, which is funded by the German Federal Ministry for Economic Affairs and Energy, is coordinated by the Institute of Robust Power Semiconductor Systems (ILH) under the auspices of Prof. Ingmar Kallfass. The team, whose members are from the ILH and IRS is collaborating with other partners including the Fraunhofer Institute for Applied Solid State Physics (IAF) as well as RPG- Radiometer Physics and Tesat-Spacecom. The objective of the three-year research project is to build a mini-satellite to test a broadband radio link to a ground station in a previously unused frequency range of between 71 and 76 gigahertz.

"This so-called E-band lies above the established frequency ranges used in satellite communications and by the military," says Kallfass. Those frequency ranges are between one and 40 gigahertz. The E-band, on the other hand, is virgin territory. Whether or not it will be possible to transmit data at high speeds in that range needs to be investigated. "The radio signal between the ground station and the satellite has to pass through the earth's atmosphere," as Kallfass explains, "which, on a clear, sunny day, is not an issue. But, due → to the many water molecules they contain, rain clouds have a major scattering effect on the signal."

However, the conditions for fast data transmissions in the E-band are not bad, because, in theory, the data rate increases with the transmission frequency due to the laws of physics. This is practical, as the ILH team has already achieved two world records in the E-band: the highest combination of data rate and distance in a radio transmission between two terrestrial sites – 6 gigabits per second over a distance of 37 kilometers and between an aircraft and a ground station at 9.8 gigabits per second. This would correspond to 120 or almost 200 DSL connections respectively at 50 megabits per second. Ultimately however, the engineering and natural sciences are not about extrapolating known data, but rather they involve the search for empirical proof – under space conditions in this specific case. The project team wants to provide this proof in the EIVE project.

Looking ahead to 2022: Space flight engineer Prof. Sabine Klinkner is building the EIVE satellite.

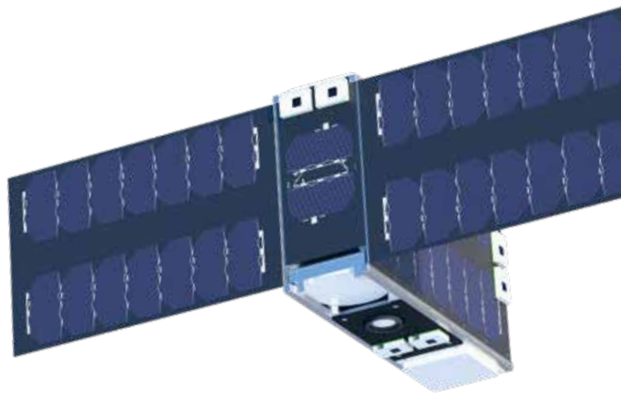
SATELLITE THE SIZE OF A SHOEBOX

The satellite is being built by Klinkner's team. "To this end we're using the CubeSat standard, which is now well-established for mini-satellites," says the professor. A CubeSat consists of cube-shaped units with an edge length of ten centimeters, which can be pieced together to form larger units similar to Lego bricks. Their great advantage is that virtually any commercially available rocket is able to transport these CubeSats in a device, which is also standardized, and launch them into space. And, because the satellites are so small, they can hitch a ride at a relatively low cost. This concept, which was established two decades ago, seriously reduces development and launch costs and makes small satellites affordable for universities. "Flying Laptop" was the name of the satellite developed by Klinkner and her team of students and doctoral candidates, which was launched into space in 2017 on board a Russian Soyuz rocket, although it was not based on the CubeSat concept.

The EIVE satellite will be about the size of a shoebox. It will be fitted with two exterior solar modules that can be folded out in space. As with any satellite, the inside will contain the electronics that enable the satellite to align and orient itself in orbit, as well as an energy storage system and radio technology that will enable the ground station to control it. The remaining volume, a good third, will be reserved for the payload i.e., the technology needed for the E-band tests, which basically consists of an antenna, several amplifiers and a video camera.

When it gets into space in 2022, the satellite will orbit the Earth at a slightly higher altitude than the International Space Station. Klinkner's team will monitor the satellite from the ground station on the University of Stuttgart campus, whilst Kallfass' team conducts the radio experiments. They want to test the radio quality in the E-band under various weather conditions, initially using artificially generated data from the satellite before going on to transmit the uncompressed video data from the camera, which will point at the Earth, in real time and at four times full HD resolution, whereby the plan is to reach a data rate of up to 10 gigabits per second. They then plan to record camera data in different places around the world, store it temporarily on the satellite, and then retransmit it to the ground station in Stuttgart when the satellite flies overhead.

"Although the E-band is considered a promising frequency range for broadband satellite communications," Klinkner explains, "there are only a few institutes carrying out empirical research under real conditions. But, with any luck, we may be the first to actually succeed." ↠



Cubist: the EIVE-CubeSat is made up of cube-shaped elements.

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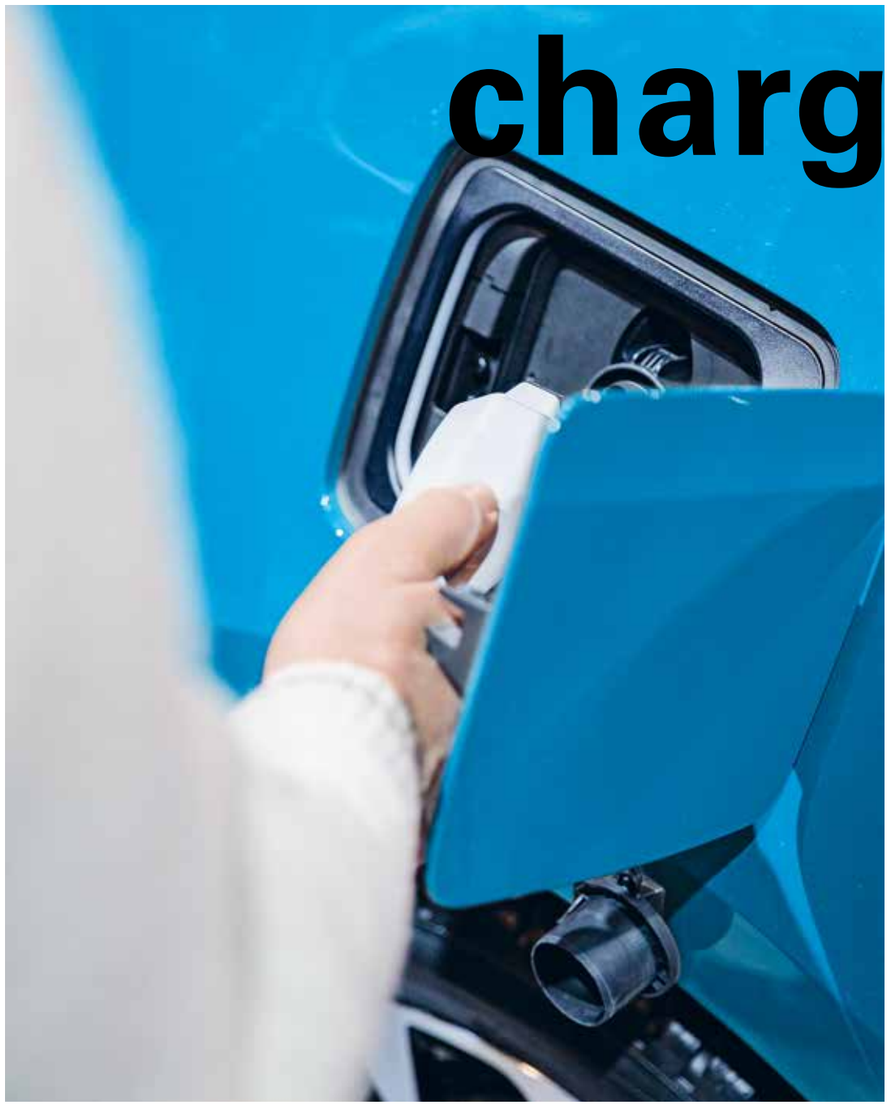
Photos: pp. 26/27 ESA/Alexander Gerst, p. 27 University of Stuttgart/IRS

Hassle-free charging battery



It's very simple: refueling electric cars is still too complicated. This makes them less attractive.

Available: the distribution of charging stations for electric vehicles is still not optimal.

TEXT: Jens Eber

Among other things, a safe, reliable and readily available charging infrastructure is of crucial importance for the broad acceptance of electromobility. Researchers at the University of Stuttgart are working on this objective in several projects.

These days, no one who drives a petrol or diesel car need fear being stranded due to a lack of fuel: any relatively modern car, will let you know when it is running out of fuel and there will still be enough fuel in the tank to get you to the next filling station even in rural areas.

Electric car drivers, on the other hand, cannot take such a "Devil-may-care" approach: their range is usually smaller in comparison and there are gaps in the charging station network. But this transitional phase will also come to an end: researchers at the University of Stuttgart are working in several projects on making e-mobility as natural in the near future as the use of combustion engine cars is today.

This is also a question of economics, as Prof. Stefan Funke, who heads up the Institute for Formal Methods of Computer Science (FMI) confirms. "We studied the question of how many charging stations would be needed, at least in the German road system, to prevent any vehicle from breaking down with flat batteries," he explains. However, because charging infrastructure is also expensive, charging stations should only be installed where they are really needed.

IDENTIFYING OPTIMAL ROUTES

Of course, being an expert in complex algorithms, Funke and his team did not simply superimpose a grid over Germany to sketch charging points in at the nodes. "There's not an unlimited supply of money for installing charging stations," says the computer scientist. So, the research group searched for the minimum number of charging posts required in the German road network, based on the assumption that the vehicles would always travel along optimal routes, which do not necessarily have to be the shortest routes. For example a short detour may lead to a route with fewer gradients. At first glance, this may sound like a manageable problem, and Funke agrees: "from a mathematical perspective, this is a very simple question to formulate."

However, the sheer number of possible routes quickly creates challenges. There are about 20 million junctions in the German road network and the researchers wanted to calculate the optimal path between each possible pair of junctions: the result is an unimaginably huge number of paths, namely 400 trillion. But the option of working with smaller networks was quickly ruled out because even calculating the potential paths for the Baden-Württemberg road network would require 93 hours of computing time and half a terabyte of memory. →

Secure: Smart Meter Gateways at the charging points can transmit data securely.

→Ultimately, the solution was to use a procedure that is also used by modern digital route planners, which involves displaying the optimal paths in compressed form in a number of pre-processing steps, which means that the route calculation can be performed later within milliseconds. Using this technology enabled Funke's team to reduce the memory requirements for the Baden-Württemberg road network to 30 gigabytes. "This enables us to approximate the optimal number of charging stations on a standard computer very well and with no deterioration in data quality," says Funke. However, the team's real focus was not on making recommendations for the placement of new charging stations, but on providing planners with the appropriate tools. Their work has been very well received in the research community. Among other things, one of their project publications on the subject was chosen from more than a thousand candidates as one of the top five submissions at conferences organized by the Association for the Advancement of Artificial Intelligence (AAAI), which is one of the two top conferences in the field of AI worldwide.

HASSLE-FREE RECHARGING PROCESS

The increasing number of e-car drivers should have to worry even less about paying for recharging than about whether their battery charge will get them to the next charging station. "They should be able to think: 'all I have to do is plug in the vehicle'," says Dr. Daniel Stetter of the Fraunhofer Institute for Industrial Engineering (IAO) in Stuttgart. To achieve this objective, eleven research partners are collaborating in the "LamA-connect" project, which is funded by the German Federal Ministry for Economic Affairs and Energy. The University of Stuttgart's Institute of Human Factors and Technology Management (IAT) is one of the project partners involved in software development, which also involves the production of charging demand forecasts, which companies could use to avoid power peaks, for example. "If the demand per charging point is known, then recharging could be done during periods, for example on sunny days, when domestic power production is high", explains Marc Alexander Schmid, an employee at the IAT, which collaborates closely with the IAO.

SMART METER GATEWAYS DEPLOYED

Another objective of the LamA-connect project is to prove that charging infrastructure for e-mobility can be controlled and monitored by smart meter gateways in compliance with the stringent security standards required by the German Federal Office for Information Security. Smart Meter Gateways are the communication units of intelligent electricity metering systems that not only record consumption but can also transmit data in a secure manner, which, in the future, would make it possible to predict when and for how long electric vehicles will remain at the charging points and how much electricity the charging process will consume. In future, these Smart Meter Gateways, which have already been standardized and are considered very secure, could also serve as a communication channel for controlling and invoicing e-vehicle charging processes. "This involves multiple technical and legal questions that the user shouldn't even have to think about," says Daniel Stetter. The aim instead is to have a system that functions very well and is available to a broad range of users, which will be tested, especially in practical situations, within the framework of the LamA-connect project. The plan is to install a charging infrastructure equipped with Smart Meter Gateways at the Fraunhofer site in Stuttgart-Vaihingen, in→

Over 136,000 electric cars were registered in Germany on January the 1st, 2020, which was 53,000 more than in the previous year.

→the Hofdienergarage multi-story carpark in Stuttgart, and in a residential area in Freiburg, whilst a lab-based pilot phase is carried out simultaneously.

Work on the closely related "LamA – Laden am Arbeitsplatz" (LamA – recharging at the workplace) project, which is funded under the German Federal Ministry for Economic Affairs and Energy (BMWi) "Clean Air" (Saubere Luft) program, began as early as July 2018. The focus of that project is on integrating charging infrastructure into everyday commercial life in cities with high nitrogen oxide levels. The project involves the installation of about 500 charging points at Fraunhofer institute premises located in a total of 18 polluted communities by September 2022. In-depth studies are also being carried out at the project's three pilot locations, Stuttgart, Freiburg and Dresden, as the Fraunhofer scientist Stetter explains, whereby, for example, the researchers want to explore ways of integrating the management of company car fleets into the overall system. Research into staff acceptance levels will also be carried out, whereby, among other things, the IAT will conduct the user survey within the framework of an acceptance analysis. →|

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Photos: GettyImages, p. 60 Fraunhofer-Institut IAO

NOTEPAD

VIRTUAL REALITY FOR THE HOME OFFICE

Simulation results or CAD data are often visualized and analyzed in a cave. However, the "social distancing" necessitated by the Covid-19 pandemic is not possible there. Visualization experts collaborating in the "Virtual Collaboration Laboratories Baden-Württemberg" (KoLab-BW) project at the University of Stuttgart and five other universities in Baden-Württemberg have developed a new software platform, which enables people working separately to collaborate in virtual environments, including from their home offices.

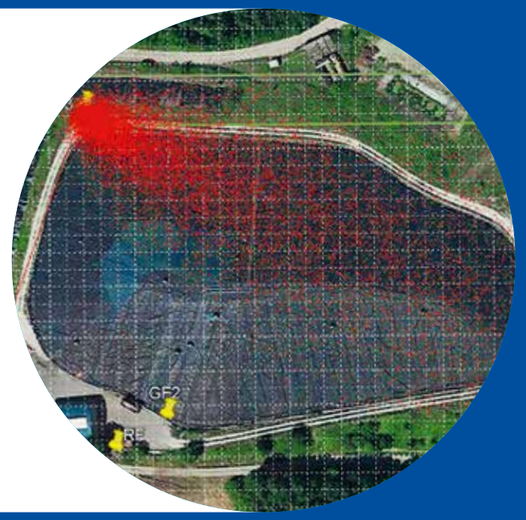
The team members meet as avatars in a virtual meeting room, equipped with inexpensive VR glasses and controllers, where they analyze 3D visualizations together. The software can help to accelerate scientific findings or to shorten the time to market for new products, and not only in the Covid-19 era; it will also be very useful in education and training.

"The team members meet as avatars in a virtual meeting room, equipped with inexpensive VR glasses and controllers, where they analyze 3D visualizations together."

CLIMATE PROTECTION BY HEAVY-DUTY DRONE

Climate-relevant gases such as methane, nitrous oxide, and carbon dioxide are released into the environment in a variety of processes and from a wide range of sources, for example through landfills or biogas plants. A new remote sensing method for recording the concentration of emissions more comprehensively has now been developed at the University of Stuttgart's Institute for Sanitary Engineering, Water Quality and Solid Waste Management, which enables a more precise modeling of their propagation. The technology consists of a heavy-duty drone and an infrared measuring method known as Fourier-transform infrared spectroscopy (FTIR).

The new measuring system can be carried flexibly to any point at a variable altitude and circle one or more emission sources. This enables a targeted and detailed measurement of the waste gas plume itself as well as the background concentrations. The mensuration flights are also fast: two to three hours on a few days a year are sufficient.



LIGHT IN THE PLUTO NEBULA

Fog forms in the atmosphere of the dwarf planet Pluto from small particles that remain there for a long time rather than raining down on the surface immediately. The first ever proof of this has been obtained by observations made by the airborne observatory SOFIA. The results were published by a team led by Michael Person of the Massachusetts Institute of Technology (MIT), which includes Jürgen Wolf, Enrico Pfüller and Manuel Wiedemann of the University of Stuttgart's German SOFIA Institute.

The new data suggests that the dwarf planet's gaseous shell is quite robust. These observations contradict earlier predictions and also explain why the veil of mist around Pluto appears blue, which is because the particles are extremely small and, therefore, scatter more blue light than other colors.

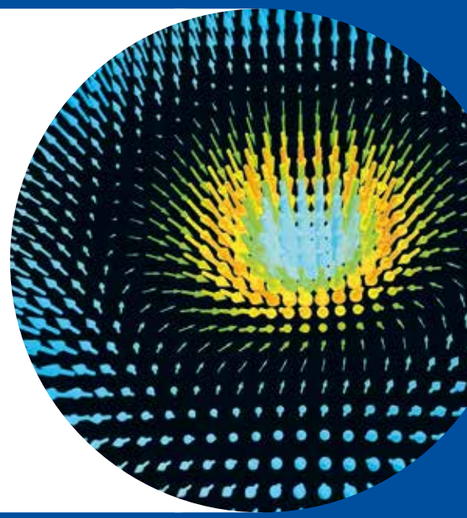
MINIATURE LABORATORY LIKE THE POINT OF A NEEDLE

While miniaturization is already well advanced in electrical engineering, analysis and process technology in medicine and biochemistry still fills entire laboratories. A group led by Jun. Prof. Michael Heymann at the University of Stuttgart's Institute of Biomaterials and Biomolecular Systems has now developed a way of miniaturizing a laboratory to the size of the point of a needle, which uses short-pulse lasers, a photoresist and 3D printing.

This method opens up a whole new era of biomedical applications. For example, the technology could be used to produce wafer-thin flexible endoscopes, which could carry out operations and investigations in the smallest of openings within the body or in machines. Likewise, the formulation of medicines can also be improved. Nature Communications https://www.nature.com/articles/s41467-020-14434-6

NANO WHIRLWINDS ON FILM

The rotational speeds in the center of a vortex are extremely high and can unfold enormous destructive forces in major tornadoes. Similar effects have been predicted for light traveling over an atomically smooth gold surface, where it could develop an angular momentum and form vortices. In a sensational piece of work, researchers from the Universities of Stuttgart, Duisburg-Essen and Melbourne, Australia have succeeded in filming these vortex patterns at the nanometer scale, which are known as "skyrmions" after their discoverer Tony Skyrme, They were even able to record the direction of the electric and magnetic field within the light in all three dimensions and to measure its movement. Science https://science.sciencemag.org/content/368/6489/eaba6415



Photos: University of Stuttgart (HLRS, ISWA, IBBS), Universities of Stuttgart, Duisburg-Essen and Melbourne, NASA/New Horizons

Cargobike rather than sprinter

TEXT: Daniel Völpel

The Stuttgart logistics model is rethinking transport and storage processes for the future, including through the use of roller coasters and cable cars. The idea is to save our cities from gridlock.

The retail world is changing, partially because customers are demanding more and more bespoke products. “This presents a huge logistical challenge,” explains Prof. Robert Schulz, head of the University of Stuttgart’s Institute of Mechanical Handling and Logistics (IFT), “because components have to be delivered in increasingly smaller quantities.” This was one of the reasons for developing the Stuttgart logistics model. “Second, living spaces, especially cities are also changing. We need to find solutions to avoid drowning in a sea of traffic.” The model is, therefore, intended to point out approaches to organizing supply and disposal in cities in an environmentally friendly and CO_2-neutral manner. It also makes use of existing technical solutions. The guiding principles of the Stuttgart logistics model are to rethink processes and to use these solutions.

What is already becoming apparent is how goods transportation is set to change in future: goods will be transported from large logistics centers close to major conurbations to small urban distribution stations, from which they will be transported to the customer over the last mile. Express parcel delivery service providers are already starting to implement this concept, says Schulz. “DHL, UPS, DPD and Co. all drive their delivery vehicles through the same streets: one has to question the sense of this.” He assumes that the political efforts to bring about a traffic transition in cities will also free up parking space. “These spaces could be used for micro-hubs.” Parcel delivery service providers could then use cargo bicycles or other emission-free vehicles to transport parcels to the customers from these centers or, alternatively, the customers could collect their goods from there.

THE ROLLER COASTER AS INSPIRATION

The trend towards personalized products is raising further questions according to the logistics researcher: “Why does the entire production process have to take place at the manufacturer’s premises? Why not move it closer to the customer?” Particularly goods that are localized for different countries, he goes on, are already being processed in the logistics companies’ distribution centers, where as Schulz says, clothing labels and emblems are applied. At the same time, 3D printing is becoming more important as a production technology and will change production chains. “Rather than first delivering all components→

The IFT checks the Koblenz cable car’s suspension and haulage ropes at regular intervals.

40,000 truck journeys per year between Nußloch and Leimen in Baden-Württemberg will be saved by Heidelberg Cement’s local freight cable car system.

→to a central factory and then distributing them to customers certain production process will be transferred to the logistics centers in future .”

This will create new intralogistics tasks: “These logistics centers will then receive a wide variety of products from different manufacturers within a very short space of time, which they will then have to distribute, sort, configure and pick or else individualize according to customer orders,” Schulz explains. These tasks cannot be done using rigid conveyor belt systems. “It requires extreme flexibility.” That is why the use of driverless transport systems, which have primarily been used in industry up to now, is likely to increase. The team at the IFT is currently looking into how these transporters could move freely within a given space and still reach their destination precisely. Among other things, they are collaborating with a start-up on an interior navigation system that uses a special radio technology.

According to the Stuttgart logistics model, when the goods leave the logistics center, they would be transported to the micro-hubs using the aforementioned technical solutions. This could be done, inter alia, by using the High-Velocity Transport System (HVTS) developed at the Institute. The idea for the HVTS is inspired by the traditional roller coaster, but the gravity-based drive system was changed.→

Prof. Robert Schulz in the IFT's cableengineering room

→The IFT team developed a new drive type: the rail has been rotated through 90 degrees and each car has its own electric motor. As Schultz explains, the team had to solve one particular challenge presented by this technology: "the flank distance between the gears changes in a curve or on a slope. A constructive development is required to ensure that this gap remains the same." The principle has already been implemented several times for leisure roller coasters, such as the "Sky Dragster" in Bad Wörishofen, Bavaria among others, in collaboration with a manufacturer. The aspiration is to use this new drive concept to transport goods and merchandise. As a logistics system, the HVTS needs to be able to transport loads of up to 1500 kilograms on standard EUR-pallets at 50 to 60 kilometers per hour and to overcome inclines of up to 45 degrees. It could, for example, also operate underground in existing sewers to provide a link between logistics centers and distribution stations. The HVTS could also deliver goods to large production facilities such as car factories and their supplier parks. However, the researchers are still in the process of developing a track system that requires less material and costs less than the steel double tracks used by roller coasters.

CABLE CARS ON THE FOREMARCH

So, Schulz has another promising means of transport in mind: the cable car. Scientists at the IFT have been researching cable technology for decades and testing cable car routes all over the world. "Cable cars would be an interesting way to link the micro-hubs with the suburban logistics centers," he muses: "I could combine the two: every third gondola would transport goods thus reducing road transport." The others, he goes on, would then be available for local public transport. "Whenever the question of how to reduce traffic congestion in cities is brought up, you're always straight back to public transport," says the logistics expert. "The cable car could play a major role in this context in the future." A good example of this is the city of La Paz in Bolivia where ten Mi Teleférico cable car routes have been in operation since 2014. More and more German cities, including Munich and Stuttgart, are also considering cable cars as a mode of transport. "Unfortunately,→this has always failed so far, partially because urban cable cars are associated with tourist locations," says Schulz. However, "the crucial thing is to integrate them into the public transport system to benefit the passengers."

Another aspect of cable cars is also difficult: "As soon as you wanted to erect a support structure here in Stuttgart, you'd meet with opposition from a relatively high number of people," Schulz fears. Nevertheless, there is a lot to be said for the cable car with it's quiet operation and unchanging drivetrain hum, practically no waiting times and: "compared with other rail systems, it is definitely the cheaper solution for the same performance." It requires no expensive tunneling, unlike a subway. By contrast with trams and suburban trains, they require hardly any space, and don't seal over much surface space. Cable cars are also largely self-sufficient, which reduces personnel and operating costs. But, as Schulz emphasizes, the acceptance problems are definitely there and need to be resolved: "nobody wants a cable car going over their residential area." So, how and where these cable cars could become established is another question that the research team wants to answer in a research project in the coming years. ↠

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Photos: p. 65 Skyglide Event Deutschland GmbH/Henry Tornow, p. 66 Uli Regenscheit

Alternative drives

Photos: Max Kovalenko

TEXT: Carina Lindig

Scientists at the University of Stuttgart are researching new drive energy systems for electric mobility. We present three promising approaches.

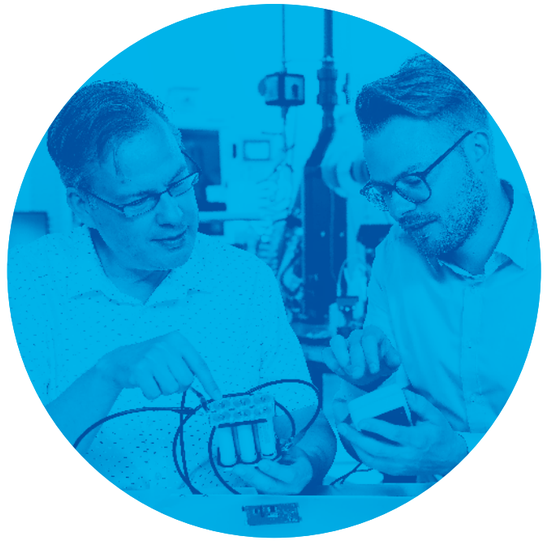
TRANSPORT IN THE FUEL CELL

The fuel cell is becoming an increasingly important drive type in the automotive sector, and, for heavy vehicles too, it is an attractive alternative to purely battery-powered drive systems. However, fuel cells need to achieve high levels of efficiency and a long service life at low cost to be able to survive in the competitive environment of the automotive industry. That is why Cynthia Michalkowski, a Doctoral Researcher at the Department of Hydromechanics and Modelling of Hydrosystemsis working on modelling fuel cells at the Sonderforschungsbereich 1313 "Interface-Driven Multi-Field Processes in Porous Media – Flow, Transport and Deformation" Collaborative Research Center. "The polymer electrolyte membrane (PEM) fuel cell consists of several porous layers all with extremely diverse properties," explains Michalkowski. These individual cells are also interconnected in fuel cells in a similar way to car batteries. The individual cells, each of which produces a voltage of up to 1.2 volts, are connected in series to achieve a higher voltage, thus forming a fuel cell stack, which is the central element in the fuel cell system. This can be researched at different levels, of which the pore scale is the smallest unit for fluid transport processes: "You zoom into a cell at the pore scale and observe the interaction between individual pores, where the transport processes take place, in detail," Michalkowski explains. A sophisticated water management system is crucial for optimizing a PEM's operating conditions, which is why Michalkowski is trying to understand the water transport mechanisms through the cell components. "I analyze the water transport from the water-repellent gas diffusion layer into the water-attracting gas distributor, whereby I first consider the interaction processes at the pore scale. I want to discover the dominant processes at the interface and how I can represent them in an efficient PEM fuel cell model." ↠

The fuel cell stack is thecentral element in the fuel cell system.

Prof. Peter Birke (on the left):

"Maximum energy density at the battery level through clever construction. And: repairs are the best form of recycling."



INNOVATIVE BATTERY SYSTEM TECHNOLOGY

The development potential of battery systems for electric vehicles is greater at the battery system level than at the cell level. This is especially true of lithium-ion batteries, whose gravimetric energy density, which indicates how much energy can be stored per battery weight unit, is particularly high . Currently, gravimetric energy density losses from the cell, the smallest single electrochemical element, to the battery system as a whole amounting to about half of the value are still typical. This is particularly true of batteries used in purely electric vehicles, as it still takes maximum effort to protect, package and cool the cell. But what this also means is that there is a high potential to increase the energy density at the storage level. Consequently, Peter Birke, Professor of Electrical Energy Storage Systems at the Institute for Photovoltaics, is looking into the idea of cutting a thread in one pole of a cylindrical cell, which would allow the cell to be used like a screw. The contact to the other pole would be achieved via the pressure of the screwed cell. Therefore, as with spark plugs, no complex welding for creating the contact is needed to obtain a functioning system. "The connection technology is stilldesigned to enable the simple, non-destructive dismantling of the Li-ion cells," Birke continues, adding that This creates the best possible conditions for them to be recycled. Birke is also testing whether modules could be easily dismantled for charging purposes, which would make it possible to simply take parts of the battery into your home and charge them via the power outlet. The modules are designed as low voltage (LV) modules, so the voltage is low enough to allow for safe charging. Birke's vision for the mobility of the future is: "Maximum energy density at the battery level through clever construction. And: repairs are the best form of recycling." ↠

ELECTRICALLY CONDUCTIVE PLASTICS

The fundamental transition of our energy supply system towards renewable energies requires efficient secondary energy storage systems. Fuel cells are a promising solution for energy transition. Prof. Bernd Gundelsweiler and Thomas Litwin of the The Institute of Design and Production in Precision Engineering are conducting research into temperature controls for thermally and electrically conductive plastics, the so-called graphite compounds, an ideal material for bipolar plates in fuel cells. "A novel manufacturing process for bipolar plates was developed in the course of this research project, which was funded by the German Federal Ministry of Education and Research," Gundelsweiler explains. The process of inductive hot pressing in concrete molds was developed by combining the interdisciplinary research areas of the various project partners. The compound, which is initially still in powder form, is heated inductively and pressed into the mold. Among other things, this process is impressive because of a significant reduction in the production cycle from 20 to about five minutes as well as the improved quality of the bipolar plates. ↠

CLEAN FLIGHT

TEXT: Michael Vogel

Air transport produces more CO_2 than any other form of transport. An international research project, involving the University of Stuttgart's Institute for Aircraft Design, is working on hybrid electric machines for regional air traffic as an alternative.

Precursor of the e-Genius HPH: The e-Genius, a battery-powered electric aircraft covered 400 kilometers.

Air traffic has doubled every 15 years since 1988. Prior to the Covid-19 pandemic, airlines and aviation experts unanimously assumed that this trend would continue over the next 15 years, and because air traffic has increased over the past three decades without having been slowed by various crises, many expect little to change in the long term despite the Covid-19 pandemic. There is a dark side to this development: according to the International Civil Aviation Organization ICAO, air traffic is responsible for about two per cent of global CO_2 emissions, which may not sound like much, but flying is the mode of transport that produces the most CO_2 per passenger kilometer travelled – 285 grams per kilometer according to the European Environment Agency EEA. The figures for road and rail transport are 158 and 14 grams per kilometer respectively.

So the aviation industry – and therefore society – has a problem, especially because, to comply with the Paris Climate Change Agreement, the European Commission has declared the ambitious target of making European air transport climate-neutral as of 2050 This is not just ambitious in view of the relevant technical challenges, but also due to the long development cycles within the aviation industry. New aircraft models coming onto the market today have been in development and undergone testing and the approvals process over a period of ten to fifteen years. Aircraft construction is not a sprint, but a marathon. →

→ “Climate neutrality cannot be achieved through more efficient aircraft and improved air traffic management alone,” says Prof. Andreas Strohmayer, who heads the Aircraft Design Department at the University of Stuttgart’s Institute of Aircraft Design (IFB). “Instead, what we need are alternative propulsion systems wherever this is technically possible.” The potential alternatives are basically the same as in the automotive industry: pure-electric, hybrid-electric, fuel cell and synthetic fuels, none of which is broadly available today. “The most advanced alternatives,” says Strohmayer, “are the purely electric aircraft, the first of which are now coming onto the market.” “The crux of the matter is their limited transportation capacity” as these aircraft are two to four-seaters.

PROGRESS IN HYBRID-ELECTRICS

Strohmayer knows what it means to build a fully electric aircraft, not least from his own experience. The Institute developed the e-Genius, a two-seater motor glider, over the past 15 years, which first took off in 2011. Four years later, the e-Genius became the first battery-powered aircraft to cross the Alps. “We achieved a range of 400 kilometers,” says Ingmar Geiß, group leader for manned aircraft projects. “But, because the energy density of the batteries is so low, it is difficult to increase the range of e-Genius by any significant amount.” They are too heavy for the amount of propulsion energy they provide,

which is why Geiß and his team are currently working on the e-Genius HPH, a hybrid-electric version of the motor glider, which is powered by an electric motor. The necessary electrical energy is provided by batteries and a generator coupled with a traditional combustion unit. The batteries are used during take-off, whereas the combustion unit is switched on during the climb phase and supplies all the necessary energy once→

The combustor unit used in the hybrid-electric e-Genius HPH is a 40-kilowatt motor from a Smart.

The FutPrInt50 vision: the IFB is coordinating an international project whose objective is to develop a 50-seat hybrid-electric airplane.

→cruise altitude is reached. “It will be one of the first hybrid-electric aircraft that really makes sense,” says the engineer. “Previous prototypes have tended to consume the same quantity of fuel as comparative craft fitted with pure combustion engines.” By contrast, the e-Genius HPH will be able to carry two people at an average speed of 150 kilometers per hour and will require no more than three liters of fuel per 100 kilometers when cruising, which is a 35 per cent efficiency increase over comparable contemporary models. With a fuel tank capacity of 40 liters, this equates to a range of 1200 kilometers. If both the battery power and fuel were to be derived from renewable sources, an aircraft such as this would operate in a CO_2-neutral manner.

IDENTIFYING TECHNOLOGIES OF THE FUTURE

“The key to designing the e-Genius HPH was finding a position for the electric motor where it would operate most efficiently,” Geiß explains. This position was located in the rear of the aircraft, whereas the 130 kilogram batteries and the generator system are positioned directly behind the cockpit. “Our hybrid-electric aircraft will be about as heavy as its all-electric predecessor, but will have over three times the range” says Geiß. The maiden flight is scheduled for this year.

So, purely battery-driven electric drive systems do have limitations. According to Andreas Strohmayer, even a 500-kilometer range would be impressive, and a range of over 700 kilometers would barely be feasible even in the future, at least without huge jumps in battery energy density innovation. This is why, in terms of significant short-distance transport capacities, the scientist, like many experts, considers the development of hybrid electric drives to be the only viable way forward in the short term. “A nine-seater plane needs a range of 1500 kilometers, whereas a 19-seater would need a range of about 2000 kilometers,” Strohmayer explains, outlining the benchmark for future developments.

A major EU project, known as Future Propulsion and Integration towards a hybrid-electric 50-seat regional aircraft (FutPrInt50), which is coordinated by Strohmayer, is looking into what the development of a hybrid aircraft would mean for aircraft manufacturers. The goal, as Strohmayer explains, is “to identify and develop technologies with which a commercial 50-seater hybrid-electric aircraft could be launched in 15 to 20 years’ time.” The project was launched on January the 1st 2020 and is scheduled to run for three years. After 19-seaters, 50-Seater planes are the next largest aircraft class and are primarily→

Prof. Andreas Strohmayer

“Don’t kid yourself”

→used in regional air traffic, where most routes are less than 2500 kilometers. “Our project involves three main pillars,” says Strohmayer: “designing an airplane, in-flight energy recovery and battery system optimization.” Simply redesigning an existing airplane will not be enough. “Don’t kid yourself”, says the researcher, “compared with a traditional jet engine, a hybrid electric drive has so many disadvantages because of its weight that you have to exploit all the advantages and synergies of electric drive systems to develop a viable aircraft concept.”

One such advantage is the comparatively low weight of electric drives, which means that electrically driven propellers do not have to be hung under the wings like giant baubles to generate the necessary thrust, but can instead be distributed along the wings at favorable positions, which, in turn, changes the optimal wing shape. Another advantage, for example, is the waste heat from the many on-board systems that contemporary aircraft do not use, which can also be improved to a significant degree. “What we want to do in the course of the project is to run various trials to prove the effectiveness of all these measures,” says Strohmayer.

TRANSFERRING RESEARCH RESULTS TO INDUSTRY

His team is responsible for the overall design and exterior shape of the aircraft, which concerns the fuselage, wings, tail unit, propulsion system, landing gear as well as mass distribution within the aircraft. “Our design already takes account of the relevant safety and approval regulations, which means that the results can actually be put into practice at a later date,” says Strohmayer.

The project budget is 4.7 million euro funded by the EU, with contributions from other partners, which increase it to 7.6 million euro. In addition to the University of Stuttgart, the EU partners include French, Italian and Dutch research institutes as well as Belgian, the Dutch and Portuguese companies. International partners include research institutes based in Great Britain and Russia and the Brazilian aircraft manufacturer Embraer. The European Union Aviation Safety Agency (EASA) and other institutions from Canada are also involved in an advisory capacity. “I’m particularly pleased that we have a manufacturer, Embraer, involved in the project,” says Strohmayer, “because, this Brazilian company builds airplanes of exactly the size we’re focusing on in this project,” a fact that the scientist hopes will greatly facilitate the transfer of research results to industry. “I’m 52: I’d love to live to see the day when I’ll be able to book a flight on an airplane for which we did the preliminary work with the FutPrInt50” ⇥

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Photos: University of Stuttgart/IFB, p. 73 futprint50.eu

Anti-wear materials

Prof. Siegfried Schmauder and the gas turbine model at the neighboring Institute of Thermal Turbomachinery and Machinery Laboratory

TEXT: Jens Eber
PHOTOS: Max Kovalenko

Higher turbine temperatures to make aircraft more energy-efficient and reduce CO_2 emissions. Researchers are constantly on the lookout for new alloys to minimize the resulting turbine damage. They can now use simulations to test their durability.

Metals are not usually associated with the verb “to creep” in the minds of most people, in fact metal is almost the epitome of stability. Nevertheless, metal creep is a real phenomenon, and depends on the temperature of the metal in relation to its melting temperature. “It starts at about half the melting temperature,” as Prof. Siegfried Schmauder, head of the Department of Multi-Scale Simulation at the University of Stuttgart’ Institute for Materials Testing, Materials Science and Strength of Materials (IMWF) explains. The higher the temperature of the metal, the more its atoms will vibrate and the stronger the vibration, the more likely it will be that atoms will change places: under a constant external stress, the metal will begin to deform.

Of course, the creep that takes place in metallic elements and alloys is not just an atomic-level phenomenon. Take aircraft turbines for example: temperatures of more than 2000 degrees Celsius are reached during the fuel combustion process inside these machines, and their components rotate at high speeds generating the corresponding centrifugal forces. The risk of wear and tear is increased if the alloys from which the turbines are made begin to creep under these conditions. Similar conditions prevail in power plant gas turbines.

EXPERIMENTS REQUIRE AN ENORMOUS EFFORT

Because wear and tear affects the cost-effectiveness of such systems as well as their sustainability, the development of robust and, above all, creep-resistant materials is a perennial task of industry. At an experimental level, this involves an enormous effort: new alloys have to be cast and tested in lengthy trials under extreme conditions. And, because it is usually not just one novel alloy that gets tested, the costs of such development processes, which are still standard in many places, increase.

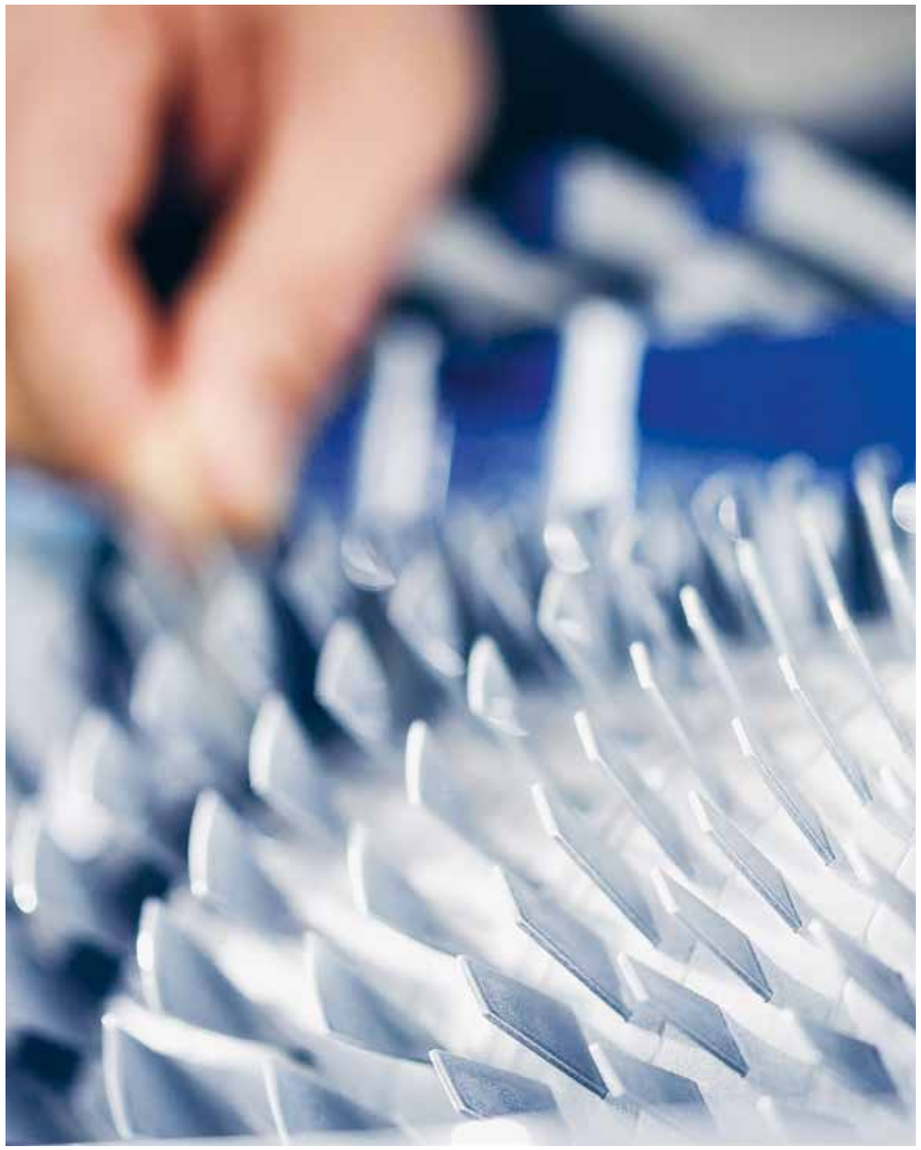
Yet the still young field of virtual materials development has increasingly been making a name for itself over the past few years. Rather than analyzing novel alloys in a long series of experiments, they are first tested in the University of Stuttgart’s high-performance computer before promising alloys are actually confirmed in physical experiments.

“All this was still a pipedream when I began my doctoral thesis in the 1980s.” says Schmauder: “Nobody believed it could work.” Even then it took several years before researchers in Stuttgart managed to calculate the formula for a new iron and copper alloy in 2008.

Several groups of researchers, working under the auspices of the Stuttgart Center for Simulation Science Cluster of Excellence (SimTech), are currently trying to identify creep-resistant alloys. One project involves research into so-called Ni-based superalloys, the main area of application of which is in turbines. These nickel and aluminum alloys are considered to be resistant to phenomenon known as atomic dislocation. →

Right: this quantum mechanical simulation of the cobalt/carbide interface represents the electron density, whereby red means low, and blue means high.

Bottom: Turbine blades



Even glass can “creep” at room temperature, but it would take many hundreds of thousands of years until the effect could be measured.

→The researchers involved in this project are now planning to use modeling to find out how temperature influences the behavior of the atoms within this alloy and under which conditions atomic dislocations occur. This special nickel alloy is particularly interesting in this context, because, to a certain extent, it forms obstacles to the dislocation at the atomic level, thus preventing creep.

“This will help us to understand how this mechanism is affected by temperature, which will open up ways of increasing this barrier as much as possible,” explains Schmauder. At the same time, the research group also wants to look into how hydrogen affects the barriers, as previous applications of the material have shown thathydrogen can have a negative influence on creep resistance.

The effects of hydrogen are also being investigated in parallel research into how the hydrogen atmosphere’s pressure and temperature affect material behavior. Theobjective is to enable the production of components that are both cost-effective and reliable, and which, for example, could be used in vehicle hydrogen tanks.

COBALT AND RHENIUM FOR PARTICLE REINFORCEMENT

In another project, in which the IMWF is collaborating closely with the TU Braunschweig’s Institute for Materials, the simulation experts are investigating a creep-resistant alloy of cobalt and rhenium reinforced with tantalum carbide, which is a compound of tantalum, a metallic element, and carbon, whereby their primary focus is on the question of how the particle amplification mechanism generated by the tantalum carbide behaves under load.

The pure cobalt-rhenium alloy is already considered to be extremely hard, but the project is based on the assumption that the alloy needs to be made even more durable for use under high temperatures and mechanical loads. “We need to find a solidification mechanism that is effective at high temperatures,” says Prof. Joachim Rösler from the TU Braunschweig: “In this project, we want to investigate the potential of metal-carbon carbides for this purpose.” To this end, researchers from both universities are carrying out simulations and experiments in parallel.

Extensive preparatory work was first needed to enable such complex simulations. “Modern computers can do a lot,” Prof. Schmauder explains, “but they’re still unable to model components at the atomic level.” The researchers used a trick to make the phenomena visible in the simulation using a proportionate amount of computing resources: they coupled calculation processes in series. “We calculate the input we need at the next level up at the atomic level,” Schmauder explains. At that level the researchers then obtain the results for the macroscopic level. ⇥

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Photo: p. 78 University of Stuttgart / IMWF

Not under 1000

Elisa Ehrlicher, who holds a master's degree in building services engineering, took part in the strategy dialog.

Jakob Dürrwächter and Juliane Heitkämper are calling for a reduction in business flights.

TEXT: Carina Lindig

Mobility, energy, health and nutrition: it is not only the public that is currently concerned about these topics; they have also long since been the subject of discussion at universities in the context of the overall public discourse. That is why 25 students and doctoral candidates who took part in the University of Stuttgart's first Strategy Dialogue discussed ideas about how to create a sustainable university.

Enthusiasm, zeal and determination were in the air at the University of Stuttgart's first Strategy Dialogue at the beginning of this year. Exploring the question: "what do you imagine the (ecologically) sustainable University of Stuttgart would be like?", students and doctoral candidates from the University of Stuttgart worked together to develop ideas relating to sustainability and climate protection using the new internal communication format. Two of the ideas presented during the strategy dialog, which was held at the Stuttgart State Museum of Natural History in Rosenstein Palace, could soon become a reality.

RESTRICTING BUSINESS AIR TRAVEL

Networking between scientists at international conferences and symposia is a prerequisite for excellent research. Yet, at the same time, the travel this involves emits a huge amount of CO_2 as Jakob Dürrwächter, who is currently completing his doctorate in aerospace engineering, explains. To illustrate the situation, he cites an example: "Over half of the ETH Zurich's emissions are caused by business trips, the overwhelming majority of which involve air travel." That is a major problem and the researchers are itching to do something about it. Together with Juliane Heitkämper, he asked himself what changes employees on business trips could make to protect the climate. "Although the number at the ETH Zurich is shocking, a great deal could potentially be achieved by reorganizing this area," says Juliane Heitkämper, a doctoral researcher, who →

Top: Change of perspective: strategy dialog held at Rosenstein Palace.

Left: Claudio Schmaus (center) calls for an improved cycling infrastructure.

Claudio Schmaus

“Perhaps you know the problem when you go somewhere by bike and you want to park it in a central, busy place, but you’re always wondering if you will ever see it again and in what condition”

→emphasizes the fact that initial approaches to solving the problem already exist: At the University of Stuttgart too, initial data relating to mobility at the university has already been collected and evaluated by the Mobility Living Lab (MobiLab). Based on the data obtained in the MobiLab (also see pp. 16/17) the situation regarding emissions can be presented to employees in a transparent manner and targets for the future can be formulated. In terms of air travel, Dürrwächter adds “We see two main ways of tackling the whole thing. For one thing, we want to avoid air travel as far as possible. And, where this is not possible, offsetting is the best approach.”

To reduce emissions, Heitkämper and Dürrwächter draw attention to the Scientists for Future’s “I won’t do it under 1000 km” campaign, which stipulates that researchers should refrain from taking flights of under 1000 kilometers. To be able to guarantee the continuation of scientific dialog in spite of all of this, the two want to create alternative discussion formats, such as video conferencing. To do this, the university would have to provide more software and hardware equipment. “What we’re currently seeing in the context of the Covid-19 crisis”, says Heitkämper, “is that meetings, seminars and even doctoral vivas can be held without the need for lengthy business trips.” The main thing, therefore, is to create a greater awareness of the issue. The doctoral students are convinced that many staff members would then take the initiative themselves and make their future business trips as sustainable as possible.

In terms of offsetting, the important thing for Dürrwächter is that the supported projects actually do reduce CO_2 emissions and that there are no “creative calculations” involved: “International certifications, such as the Gold Standard, ensure that greenhouse gas emissions are actually offset at the desired level and require risk assessments of negative side-effects.” Alternatively, the University could establish local projects, at least to some extent. “For instance,” Heitkämper and Dürrwächter suggest, “we’d like to initiate an inter-faculty competition in which prizes would be awarded for the lowest total flight distance, the greatest reduction or the highest offsetting.”

BICYCLE LOCKERS ON THE CAMPUS

Claudio Schmaus from the Infinity university group has drawn up a detailed proposal for an emission-free campus. “Perhaps you know the problem when you go somewhere by bike and you want to park it in a central, busy place, but you’re always wondering if you’ll ever see it again and in what condition,” he explains vividly. To solve the problem, he and his team would like to install bicycle lockers on campus, in which people could lock away their bikes. As Schmaus explains, there are different locker designs to choose between, so there would be sufficient space for many bikes within a small area. It would also be possible to plant greenery on top of the lockers. Another benefit, he adds, would be that you would also be able to store a bike helmet or a bag in the locker. The electromobility student underlines the fact that the lockers are easy to use: “Reservations can be made via an app. But mechanical alternatives are also possible.”

To bring about a cultural change on the Vaihingen Bicycle Campus, he adds, we need to focus on the necessary infrastructure, and the university would have to provide students and staff with access to shower rooms. How soon these recommendations will be implemented remains to be seen, but one thing is certain: sustainability and climate protection will be a permanent aspect of campus life going forward. ↠

Photos: University of Stuttgart / Max Kovalenko

PURPLE BACTERIA FOR GREEN HYDROGEN

Prof. Robin Ghosh wants to contribute towards halting climate change.

TEXT: Jutta Witte
PHOTOS: Sven Cichowicz

Hydrogen burns without releasing CO_2 and there are many ways of using it as an energy storage medium, but it has always been complex and expensive to produce. A research consortium, at the University of Stuttgart headed up by Englishman Prof. Robin Ghosh, is hoping to optimize a new biological process, known as dark photosynthesis, for industrial applications.

In the view of Prof. Robin Ghosh, Head of the Department of Bioenergetics at the University of Stuttgart's Institute of Biomaterials and Biomolecular Systems (IBBS), the first element in the periodic table is the crucial one for saving our planet: "The success of the energy transition will depend on whether we will be able to produce hydrogen in sufficient quantities," he says. Ghosh is a recognized expert in biochemistry, biophysics and microbiology. Prior to his appointment at the University of Stuttgart in 1996, he spent 16 years at the University of Basel's Biozentrum for biomedical research, the ETH Zurich and working on behalf of the pharmaceutical company Hoffmann-La Roche, where he mainly conducted research into the structures and building blocks of cell membranes. During the course of his career, one thing has become increasingly clear to Ghosh: not only are bio-organisms versatilelife forms, but they can also produce hydrogen. The 65-year-old scientist has been committed to exploiting this ability to promote the biological production of the coveted molecule for many years: "If my research can make a contribution towards fighting climate change, however little it may be, I'll do it."

Because H_2 has enormous potential for such things as fuel for aircraft, ships, and fuel cells, for the production of raw materials for the chemicals sector and for firing furnaces in the steel industry. To exploit this potential, the German government is primarily focusing its national hydrogen strategy on green hydrogen that can be produced without the use of fossil fuels.

But, extracting or capturing the gas is a challenge, because it only occurs in nature in bound form, as a component of water and nearly all organic compounds. Almost every living organism is a potential hydrogen source. Electrolysis, a technically mature process that uses the surplus electricity from wind turbines or solar power farms to split water into oxygen and hydrogen, is the most common process to date for the production of green hydrogen. In addition to this thermochemical method, long-term research and development has also been carried out in relation to biological production processes, which exploit the metabolic processes of algae and bacteria to capture the hydrogen produced during complex chemical reactions. However, the relevant technologies are still in the research or pilot stages. "We don't yet have marketable and affordable processes," explains Ghosh.

THE "EXOTIC" AMONG THE BACTERIA

Like green plants and algae, bacteria can also use photosynthesis to grow by using light energy to convert water and carbon dioxide, which they absorb from the atmosphere, into the components they require for growth, a process during which they also release hydrogen. The challenge now is to influence the metabolism of these microbes to maximize their hydrogen production. At the head of the RhoTech research association, which is funded by the German Federal Ministry for Economic Affairs and Energy (BMWi), Ghosh's team are betting on Rhodospirillum rubrum a species of purple bacteria that usually lives in ponds and puddles and which thrives best at very low oxygen concen-→

The bacterial mutants on culture medium plates have characteristics in which Prof. Ghosh is interested.

Redox reaction:
this term is an abbreviation for reduction-oxidation reaction, in which a reducing agent releases electrons to an electron acceptor.

The small growth flasks contain the culture medium for dark photosynthesis.

The purple culture of the Rhodospirillum rubrum bacterium has grown by dark photosynthesis.

Photosynthetic pigments are analyzed spectroscopically.

→trations, unlike other bacteria. Hardly anyone in the scientific community is more familiar with it than Ghosh, who has been analyzing every aspect of this "exotic bacteria" for 26 years. "It's as versatile as a Swiss Army knife," he says. The range of potential applications include everything from the production of vaccines to animal fodder. The fact that it can also produce H_2 in quite significant volumes was discovered quite by accident when a flame suddenly sprang from the fermenter during the cultivation of the purple bacteria.

USE WASTE PRODUCTIVELY

Ghosh has been consistently pursuing this idea since then. He is now planning to develop a technological solution over the next three years, which is already well understood from a basic research perspective, and works at the laboratory scale, in collaboration with his consortium partners – the biotechnologist Prof. Hartmut Grammel of the Biberach University of Applied Sciences, Prof. Alexander Sauer, head of the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) in Stuttgart, and KE-Technologie GmbH, specialists in welding technologies with a presence on the Vaihingen campus. The eventual objective is to enable the production of biohydrogen on an industrial scale using a variant of photosynthesis known as dark photosynthesis. The "M2SF" culture medium, which was developed by Ghosh serves as the crucial component, providing the energy, initiating the metabolic process, and also supplying the necessary carbon. In addition to succinic acid and various salts, it mainly consists of fructose obtained from fruit and dairy waste. →

→ "There is a problem with all previous artificial photosynthesis processes," Ghosh explains: "They are based on the assumption that light will be used and that carbon dioxide from fossil fuels will be available." However, light is reaching its limits as an energy source for photosynthesis in industrial plants and the volume of CO_2 that can be produced from fossil fuels is finite. According to the expert, it has only been possible thus far to produce relatively small cultures of up to 200 liters using such processes. "If serious use is going to be made of hydrogen in the energy mix of the future, we'll need a technology capable of producing bacterial cultures of up to 100,000 liters." This is where the purple bacteria come in. The experts have come up with a trick to boost its growth in the laboratory whilst simultaneously using a photosynthetic process to produce hydrogen. The fructose contained in M2SF enables redox reactions which produce H_2, which can otherwise only take place in the presence of light. "The bacterium 'believes' it is using light to grow, but in reality it isn't," says Ghosh. "Dark photosynthesis makes us light independent, and we can use it to produce cultures of almost any size." The process has even more benefits: abundant amounts of fructose, the key ingredient for this type of H_2 production, are available in the form of waste products from the fruit juice and sugar industries, but also from dairies, and can now be used for the production of green energy. Dark photosynthesis also produces other products, in addition to hydrogen, such as terpenoids and carotenoids, which can be used in the food and pharmaceutical industries.

FROM LABORATORY TO INDUSTRIAL SCALE

Ghosh and his team are currently able to produce culture volumes of 40 liters in the laboratory. The RhoTech partners are working on various details to scale up the new process. The IBBS researchers hope to genetically modify the purple bacterium and configure its regulatory mechanism to maximize its H_2 production and enable it to grow stably in large industrial plants. The Fraunhofer IPA is focusing on the analysis of the available biomass and developing production topologies and use scenarios. The Biberach University of Applied Sciences is concentrating on optimizing the process for the pilot plant, which will begin industrial scale operations at the end of the project. And industrial partner KE-Technologie GmbH is working on energy-saving supplementary LED-based lighting to further increase the hydrogen yield. "Dark photosynthesis is an important building block for the success of a future hydrogen economy," Ghosh emphasizes. He now wants to get this building block ready for wide-scale deployment: "We're ready." ⇥

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DR. PETER SCHÄFER

THE BEST OF TWO WORLDS

INTERVIEW: Daniel Völpel

Engineers from Porsche Engineering Group GmbH in Weissach are working on how vehicles could drive electrically, and in a networked and autonomous manner. Dr. Peter Schäfer, CEO and alumnus of the University of Stuttgart, talks about the high expectations for future mobility.

Mr. Schäfer, may we take a look around your development laboratories: what does the Porsche of the future look like?
PETER SCHÄFER For the customer, the essential features of Porsche quality are incomparable design, driving feel, ergonomics, and performance. We want to carry these genes, as we call them, into the future, whilst taking account of the new ecological and social conditions, which means consistent electrification, as featured in the Taycan, our first electric vehicle. Connectivity with many new functions based on big-data technologies and artificial intelligence is also another consideration.

How is the work divided between you and your clients?
PS As a traditional engineering services provider with a focus on development, we work both on behalf of Porsche, our parent company, but also for other companies. Vehicle manufacturers outsource certain components or even entire projects to service providers. We work on these up to an approval recommendation: final apprroval and type testing are then done by the manufacturer. We at Porsche Engineering place particular emphasis on new software-based functions in addition to the development of complete vehicles and systems. New functions could be implemented with the aid of AI and cloud-based data for example. For instance, the control system can be adapted to the current road conditions by recording them within the vehicle. Predictive driver information would even be conceivable if this were to be combined with data from other vehicles and, for example, with weather information from the Cloud. . →

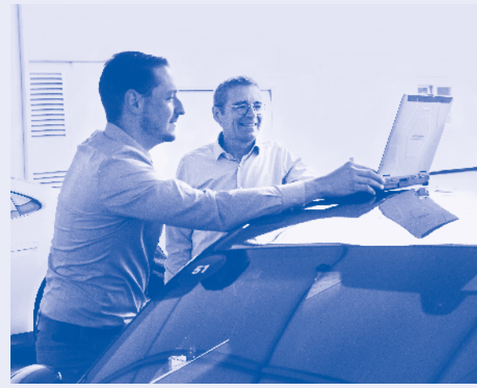
→ "Porsche" is included in your company's name: given current trends, such as driver assistance, networking, and e-mobility, where will sports cars and their petrol-head drivers fit in in the future?
PS Of course, our target customer, who influences the development of our vehicles is the kind of driver, whose main focus is on the experience and driving pleasure. You can get all that on special tracks. A lot of fans do that. But perhaps you also want to benefit from the vehicle's dynamics on a twisty mountain road in the Black Forest. Moments like that are very precious to the owners. We know that customers will only be able to drive their cars that way for short periods in the future, which is precisely why such experiences have to be even more intense. And that's exactly why we develop the vehicle in such a way that it masters these characteristics, knowing very well that, in their everyday lives, our customers will often be stuck in traffic jams just like everyone else. In those situations, we need the assistance and support functions that make these traffic conditions as pleasant as possible for drivers and passengers. So it's the best of both worlds: the ultimate driving experience, wherever and whenever possible, and the maximum level of comfort in everyday driving situations.

So, a car should fulfill as many different roles as possible?
PS Yes! We refer to this as the spread between driving dynamics and comfort, between the driving experience and everyday road capability. Our aim is to maximize the spread of our cars.

Speaking of spreading: the public is clamoring for quieter, smaller, and – ideally – zero-emission cars. Your customers want big cars with plenty of room, rapid acceleration, speed and range. Can you reconcile those things?
PS If our customers like sporty SUVs, we want to include these in our range. The best way to achieve compatibility with environmental considerations is with hybrid or fully electric vehicles, which can produce zero emissions using a combination of electric drives and green electricity. That's why we're incorporating a pronounced electromobility aspect in our products. Batteries have a lower energy density than fossil fuels, which is why the question of efficiency is even more relevant for electric vehicles. It's a balancing act, but we're taking on this very exciting challenge.

As an external service provider, do you have more freedom in terms of concept and design or are the manufacturers' specifications really strict?
PS Both. Manufacturers generally award contracts based on a clear specification of the product to be delivered. However, there are certain developments for which we need to take greater libertiesand can contribute many ideas and suggestions. That's why – not only in relation to our customer projects but also to our own technological developments →

"Our aim is to maximize the spread of our cars ... between driving dynamics and comfort, between the driving experience and everyday road capability"



Peter Schäfer (right) believes in new software-based functions.

→– we put a lot of thought into the question: what will our customers care most about in the future? Our response is to acquire skills, for example in high-voltage or charging technology or in data analysis and artificial intelligence, at an early stage.

So you also develop new vehicle technologies even in the absence of a customer order?
PS Yes, we allow ourselves that freedom to a limited extent, but we choose which technologies to focus on very carefully. And I'd like to point out that we've made the right choices in the past by focusing on electromobility, networking and autonomous driving functions at an early stage.

As an alumnus of the University of Stuttgart, which of your findings from your time as a student and doctoral candidate do you still find particularly helpful?
PS For my PhD, I was very fortunate to be able to work on a topic relating to the use of mechatronics even all those years ago. In those days, mechatronic systems consisting of actuators and sensors as well as electronic control units that enable a range of novel functions, were being integrated into traditional vehicle technology based on mechanics, hydraulics and electrics. My PhD supervisor, Professor Werner Schiehlen, stressed the fact that we need to explore the combination of mechanics and software and that we need to find ways of integrating and testing mechatronic systems. That has had a major impact on my professional career.

The University of Stuttgart collaborates closely with industry. What do you regard as the University's role in this?
PS Without a doubt, their primary task is to train, promote and prepare talented youngsters for their early careers, which would include familiarizing them with future-oriented technologies, sustainability and climate protection. These are the topics that really move us. In my view, tackling the challenges of tomorrow requires a close dialog with industry – on the industrial side we're concerned with applied science and engineering, whereas the University's concern is basic research, always one step ahead. To this end, we always need to find a balance between making the right contribution towards the further development of our technologies and of Germany as a center of industry, and meeting our social obligations with regard to the environment, climate and social issues. →|

DR. PETER SCHÄFER

After studying mechanical engineering and completing a subsequent doctorate at the University of Stuttgart, Peter Schäfer worked in the field of chassis engineering for both Ford and Volkswagen AG. He joined the Porsche Group in 2003, where, among other things, he was Managing Director of Porsche Engineering from 2004 to 2009. After that he was in charge of the Chassis and later the Complete Vehicle/Quality Sections within Porsche AG's Development Department. He took over as Chairman of the Board at Porsche Engineering in July 2019.

Photos: Porsche Engineering

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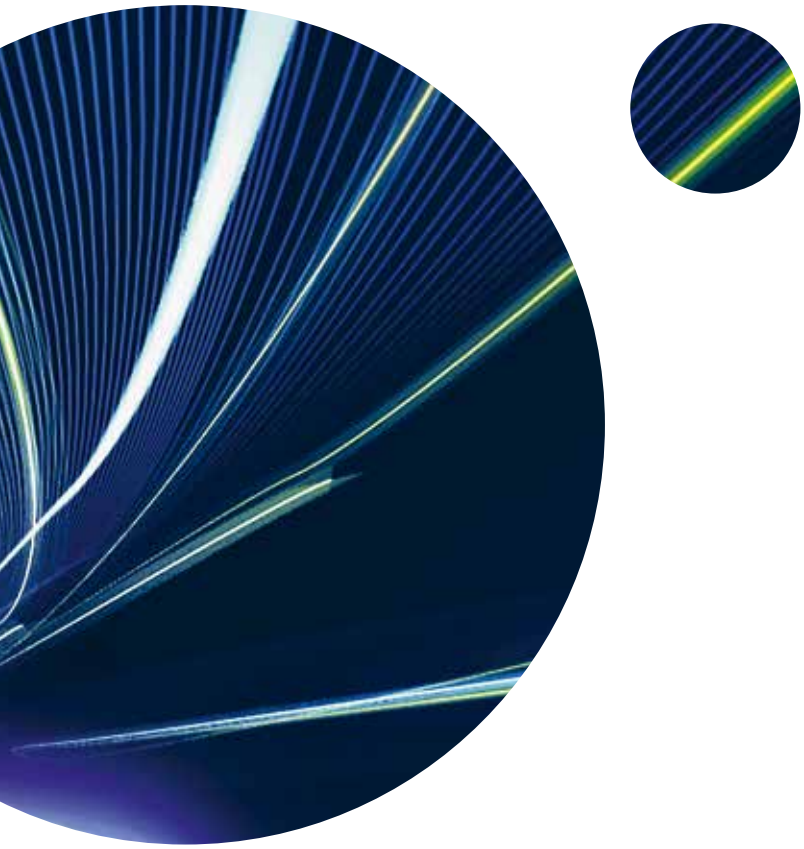

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