Faszination **Forschung**

TUM Research Highlights
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Smart Mobility

Intelligent Traffic Systems – Digital Twins Improve Safety and Convenience
Automated Driving – We Need a New Traffic Culture
Electromobility – Simulating Singapore's Power Grid

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Dear TUM friends and associates,

The standstill caused by the coronavirus crisis has ultimately brought about a renewed sense of momentum. Lockdowns made many people aware of the importance of mobility, while others benefited from not having to travel and discovered alternatives. Numerous cities around the world seized the opportunity to implement street use experiments, promoting alternative traffic concepts and creating spaces for people to meet, play and engage with culture in public areas.

The COVID lockdowns and the global climate crisis have brought home precisely how important it is for mobility and goods transport to become more climate-friendly, low-noise, low-emitting, intelligent and connected in the future. If Germany hopes to remain a pioneer in the field of mobility, we must exploit this newfound positive spirit of forward moving dynamics! This will call for transformative approaches in the development of high-performance electric and fuel cell-based drive systems, AI-assisted communication and control systems, and new digital business models such as Mobility-as-a-Service and ride-sharing. In addition, it is vital that we embed new forms of mobility into existing infrastructures and integrate them into highly livable urban design. Ultimately, this new mobility must not be the result of a new culture of self-denial – quite the opposite, it needs to be convenient, pleasant and enjoyable!

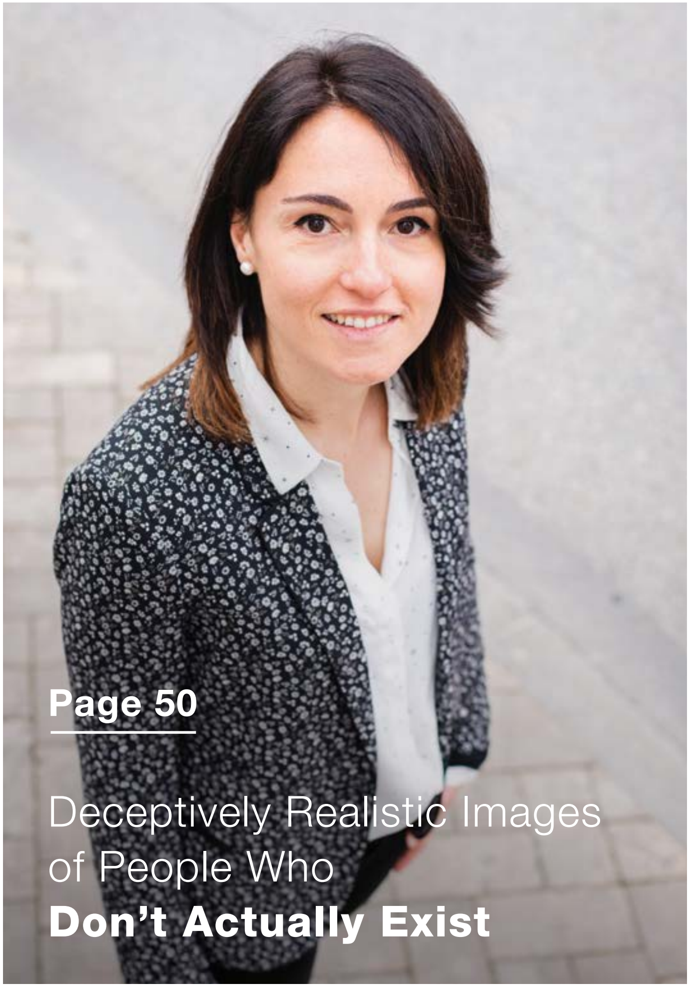
While parked (!) and moving vehicles currently take up the major share of public space in our automobile-centered cities, the coming mobility transition must focus squarely on people, their interests and the different groups who use mobility services. We must therefore summon the courage to redraw the map and pursue a strategic culture of innovation in pursuit of our mission, bringing together leading regional stakeholders to develop a sustainable, digital mobility system unencumbered by disciplinary, institutional or ideological limitations. Policymakers must create suitable incentives; cities and municipalities need to adopt intelligent space utilization concepts; research and industry will have to develop and implement pioneering technologies – while ordinary citizens must be actively involved in every aspect.

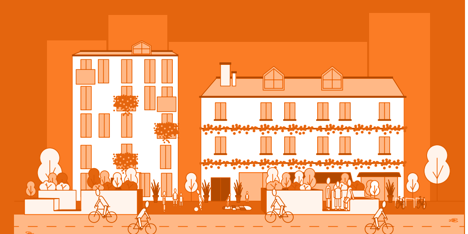
This issue of Faszination Forschung is dedicated to the topic of smart mobility. In the TUM.Mobility research platform and the BMBF-funded Munich Cluster for the Future of Mobility in Metropolitan Regions (MCube), TUM has already concentrated its mobility-related resources to form a strategic focus. I am delighted to share some fascinating insights with you into the ideas, goals and achievements of our ingenious researchers.

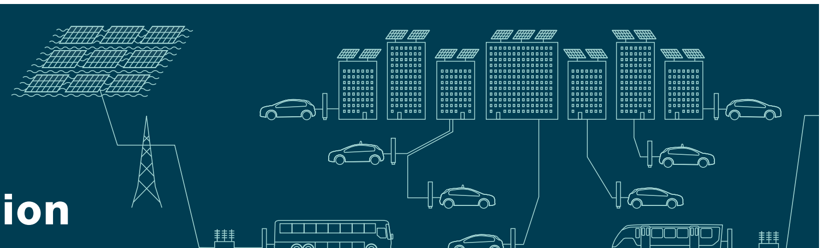
Yours sincerely,

Thomas F. Hofmann
President

Picture credit: Astrid Eckert







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D	**German edition available as a PDF here**:
	www.tum.de/faszination-forschung-28

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Picture credit: Juli Eberle

“We need to find different incentives”

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Interdisciplinary thinking is the key to developing new mobility concepts – that’s the view of automotive engineer Prof. Markus Lienkamp, political scientist Prof. Miranda Schreurs and traffic planner Prof. Gebhard Wulfhorst.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

„Wir brauchen andere Anreizsysteme“

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Der Fahrzeugtechniker Prof. Markus Lienkamp, die Politikwissenschaftlerin Prof. Miranda Schreurs und der Verkehrsplaner Prof. Gebhard Wulfhorst sind sich einig: Fachübergreifendes Denken ist der Schlüssel für die Entwicklung neuer Mobilitätskonzepte. Smart Mobility bedeutet für sie, vernünftig unterwegs zu sein mit einer Mobilität, die klima- und zeitfreundlich ist und Spaß macht. Sie sehen eine Zukunft, in der weniger Fahrten stattfinden, mit mehr Insassen pro Fahrzeug und – gerade in den Städten – mehr Mobilität mit dem Fahrrad oder zu Fuß. Verbesserung von Luft, Raum und Zeit, so bringt es Lienkamp auf den Punkt. Ohne die Einbeziehung der Bürgerinnen und Bürger wird es nicht gehen, sagt Schreurs. Die Gesellschaft muss sich mit Mobilität auseinandersetzen und sich fragen, was sie erreichen möchte, meint sie. Smart Mobility ist nicht nur eine Technologielösung, erklärt Wulfhorst. Die Konzepte können nur dann erfolgreich sein, wenn sie in ein öffentliches Verkehrsnetz, den öffentlichen Stadtraum, integriert werden. □

What does “smart mobility” mean for you?
Gebhard Wulfhorst: In Munich, we would say, “gscheit mobil” – mobility needs to be enjoyable and reliable. It is more than just a technological solution. Public acceptance and strategic planning in municipal politics are critical. That is why we are linking multiple disciplinary perspectives when we research mobility at TUM through our TUM.Mobility research platform.

Miranda Schreurs: It’s not just about getting from A to B, it’s about how we can create a climate-compatible and eco-friendly system while also actively integrating business and local citizens’ perspectives. Smart mobility is a sensible use of mobility solutions; it is environment-friendly, efficient and based on forward-looking technologies.

Markus Lienkamp: I’d like to highlight three points about our research. First, our Smart Mobility research team is recording and analyzing how people get around. Second, we are striving to improve the quality of air, space and time. Third, we want to prevent unnecessary journeys. For those journeys that need to happen, we need to increase occupancy levels above the 1.3 people transported on average per vehicle today.

Terms such as “transport transition” and “mobility transition” have become commonplace in public discourse. How would you define them?
Wulfhorst: I would differentiate between a drive transition – that is, a change in the technical and energy-related aspects of transport – and something I would refer to as a mobility shift. The term “traffic” refers to people and vehicles moving from A to B, including on foot. “Mobility” is a much broader term; it incorporates use of space, personal circumstances and social aspects.

Lienkamp: There is a common perception that all we need is a switch from combustion engines to electromobility. But this is a misperception. While this is a small part of the solution, it is only a very small part. If we want to achieve 80 % decarbonization of the transport sector through electromobility alone, the costs will be enormous. What we need to do is to take cars off the roads, expand local public transport networks, and encourage active mobility, such as walking and cycling.

Schreurs: Decarbonization is an important part of the solution from an environmental perspective. Another issue is about how we use space. Cities are full of ▷

"It's about how we can create a climate-compatible and eco-friendly system while also actively integrating business and local citizens' perspectives."

Miranda Schreurs

Picture credit: Juli Eberle

parked cars. We need to consider: How can we go shopping responsibly? How can elderly people get around cities easily? All of these facets are part of the transition that is so vital for us.

Wulfhorst: Actually, it's about arriving at the right place at the right time. That's why we're currently working on accessibility planning. An example would be the concept of a 15-minute city in which all key amenities – supermarkets, kindergartens, and so on – are reachable within 15 minutes of the place you live.

Lienkamp: Just think about how time-consuming mobility is for so many. Take my day today, for example. It only took me 5 minutes to cycle to the university. I went home at midday and did a little shopping on the way back here. After that, I cycled 10 minutes to where I go horse-back riding. That means that by the end of the day today, I won't have driven a single kilometer – instead, I'll have spent 40 minutes on my bicycle, enjoyed myself in the process and gotten everywhere I needed to be on time. Other people might take as many as 3 hours to make the same journeys because they live far away. Deciding where we live and work determines a great deal about our mobility and our use of time. ▷

Prof. Dr. Miranda Schreurs

researches environmental, climate and energy policy. She studied at the University of Washington, the University of Michigan and, thanks to a Fulbright scholarship, Keio University in Japan, before spending three years researching at Harvard University's Kennedy School of Government. From 2007 to 2016, Schreurs headed up the Research Center for Sustainability (FFN) at FU Berlin. She has held the Chair of Environment and Climate Policy at TUM's Hochschule für Politik since 2016.

Prof. Dr.-Ing. Gebhard Wulfhorst

studied civil engineering at RWTH Aachen. He furthered his interest in urban and transportation planning at the École Nationale des Ponts et Chaussées in Paris. After obtaining his doctorate from RWTH Aachen, he moved to Strasbourg in 2004 to take up a position as a Marie Curie Fellow at the EU Commission, and later worked for a planning agency in Karlsruhe. He has led the Chair of Urban Structure and Transport Planning at TUM since 2006.

Prof. Dr.-Ing. Markus Lienkamp

has led the Institute of Automotive Technology at TUM since 2009. His research focuses on autonomous driving, electromobility and other mobility topics. After studying mechanical engineering at TU Darmstadt and Cornell University, Lienkamp obtained his doctorate in Darmstadt. This was followed by a position at Volkswagen, where he led the “Electronics and Vehicle” department in the Group Research division before moving to TUM.

Picture credits: Juli Eberle

What other challenges do we face when it comes to mobility? We've already mentioned the climate crisis, traffic congestion, space and time problems.
Lienkamp: In a nutshell, it's about improving the quality of space, air and time.

Wulfhorst: Social sustainability and affordability are issues that are often overlooked. We have to ask, who will be the winners and who the losers? And we have to pay attention to how can we provide safety for poorly protected groups in traffic.

Lienkamp: There are too many situations where gas prices don't really influence driver behavior because users don't feel the costs. When it comes to company cars, for example, it's the companies that pay for the fuel.

Lienkamp, Wulfhorst and **Schreurs** simultaneously: We have the wrong incentive systems.

Prof. Lienkamp, as an automotive engineer, you specialize in vehicles. So, why are you advocating so strongly for a reduction in car traffic?
Lienkamp: The term "vehicle" is overarching; it includes bicycles, motorbikes, trucks, buses, and so on. We will still need cars, of course, but I would seriously question whether we still need so many cars. Take Singapore for example: They have 5 million residents but only a million cars. Traffic flows well, as cars are expensive and their numbers are limited. And the flexible congestion charge increases when traffic begins to flow more slowly. Translating this to Munich with 1.5 million residents, this would mean that we should only have 300,000 cars on the road rather than the current 750,000.

Schreurs: We often look to Singapore and other cities that have already developed a certain image in terms of mobility, such as Copenhagen and Amsterdam for cycling, or Vienna for completely novel concepts for a city with fewer cars. I ask myself how we can achieve something like that for Munich. Creating a location that is genuinely future-oriented, develops exciting concepts and attracts young people – these are important goals.

"What we need to do is to take cars off the roads, expand local public transport networks, and encourage active mobility, such as walking and cycling."

Markus Lienkamp

TUM.Mobility –
an interdisciplinary research platform

TUM.Mobility combines the expertise and resources of 40 professorships in various disciplines, facilitating interdisciplinary collaboration at TUM on the future of mobility. It aims to address global social challenges with a holistic approach in order to develop successful innovations, generate momentum for economic transformation processes, bring about socially fair mobility systems, and minimize the environmental pollution and health impacts of transport.
TUM.Mobility covers eight main topic areas: urban mobility, low-carbon power systems, autonomous driving, integrated transportation systems, urban development, transport modeling and simulation, governance and participation, and business models and entrepreneurship.

www.mobility.tum.de

How can we get there?
Schreurs: Munich and Bavaria have some ambitious targets but we haven't always achieved targets we've set in the past. One problem is that political decisions don't always match the interests of industry and society. We need to find ways to convince policymakers and industry to embrace changes that also incorporate citizens' perspectives; we should develop mobility ideas together. That's where the university can play an important role.

Wulfhorst: Trying things out helps a lot. The coronavirus pandemic has given us all a more flexible mindset. This has also been applied to our city streets. Right next to our office in downtown Munich is Theresienstrasse, a two-lane, one-way street. Although there were plans for a third lane to go in the opposite direction, during the pandemic the city authorities instead replaced one of the traffic lanes with a pop-up cycle lane. After some controversy, a court decided that the cycle lane can stay permanently. So, a transport transition has already taken place here and will likely occur in many other places too. Through our EU-funded project, Street Experiments, we see that there is a strong European trend toward more room on the roads for cyclists and less for cars.

Schreurs: That's a great example – we need much more of that. A lot of innovative concepts have been created here in Munich and it's important that we actually implement them, too. If we do, Munich can become a model for others.

Prof. Lienkamp, what are your expectations for autonomous vehicles? Could you briefly explain two terms for us: autonomous and automated?
Lienkamp: Autonomous vehicles don't have a driver; automated ones do, but the vehicles perform certain tasks. Simply automating every car won't achieve anything. We need to think about things differently. Automation will allow us to replace sparsely occupied 50-seater buses with more compact, autonomous transport vehicles that carry smaller numbers of passengers. These will be considerably more flexible and will be able to overcome one of the major drawbacks to local public transport – long journey times due to the sheer number of stops – in an affordable way. In our experience, you need an average of 4 to 6 people per journey to make this system work. For Munich, we've calculated that if we were to get rid of all private car traffic and replace it with small shuttles, we would need at most 16,000 vehicles. We're actually not so far from that already, as Munich currently has 3,300 taxis.

▷

Picture credit: Juli Eberle

"Society needs to discuss mobility much more and ask itself what it wants to achieve." Miranda Schreurs

Prof. Wulfhorst, you've said that, for many new mobility technologies, we need to take the public realm into account. What exactly do you mean by that?

Wulfhorst: That's the finding of our projects, particularly for the European context. There, the focus is on start-ups, technological development and economic success. We believe that new mobility concepts need to be integrated with a public transport network serving the urban public space. There are also legal issues to consider. For example, streets are a common good. We need to be mindful of who is using them and for what purposes. What we certainly don't want is to develop a system where children can no longer walk to school because autonomous shuttles, sharing services and so on are taking up so much room that the remaining space is unsafe. Car sharing and shuttle services will only contribute to genuine sustainability when they are connected with the local public transport network via mobility stations. In the future, regional authorities will have to provide these kinds of private services as supplementary mobility services at these hubs, just as they do with buses today.

Schreurs: Sharing concepts are becoming more popular but there are not enough cars available. That is why car sharing is not particularly easy to use. Many people continue to reject car sharing due to a lack of vehicle availability.

Lienkamp: If a lot of people were to use sharing services, the networking effect for everyone would be a huge advantage. It would ensure that there are plenty of locations where you can find shared cars and this would make car sharing convenient.

Prof. Schreurs, you conduct research into environmental and energy policy. Electromobility is the key to harnessing renewable electricity for use in transport through sector coupling. Germany aimed to have a million EVs on the road by 2020 – and missed this target. What do you see as effective levers we can pull to bring about a mobility transition?

Schreurs: The horrific situation unfolding in Ukraine should be taken as an opportunity, even a necessity, to rapidly reduce our gas consumption (we spoke early April – Ed.). This means we will have to change our thinking significantly. We also know we're facing a climate crisis. The younger generation is genuinely fearful for their future. Yet crises create new opportunities. We have a window open for change right now if we choose to use it. Decision-makers in the worlds of politics, industry and NGOs must come together to review existing concepts and discuss alternatives for the future, before then implementing them expeditiously.

For that to happen, the right incentives must be in place. Public transport needs to be cheaper, company cars more expensive, and shared mobility more attractive. We must rethink our priorities. To date, our priorities have been individual freedom tied to private cars. Society needs to discuss mobility much more and ask itself what it wants to achieve. I don't know how many people are actually engaging with the idea of autonomous, shared vehicles. However, if society doesn't consider it a viable concept, it will be very difficult to implement. Technological development should not take place in the lab but rather in dialog with society. We need to come together to discuss which direction we want development to go – whether we want to invest in a certain technology and, if not, to look for alternatives. ▷

Picture credit: Juli Eberle

"Streets are a common good. We need to be mindful of who is using them and for what purposes." Gebhard Wulfhorst

Do you think we need more citizen engagement, perhaps in a different form?
Schreurs: Citizen engagement is hugely important. There are already a few excellent examples; for instance, there were eight citizens' conferences held as part of the Bavaria 2030 survey. We should have similar town hall-type meetings across Bavaria. We should discuss various mobility options for municipalities, urban districts, and rural communities. Digital twins for regional mobility would be good, so that people could consider different alternatives directly.

Lienkamp: One goal would be to convince people that, while they obviously need access to mobility, this does not necessarily mean a car of their own. There was a study in which participants were paid to stop using their cars for a period and to instead use other mobility options, such as public transport. After the study, two-thirds of the participants indicated they planned to do away with their cars.

Schreurs: That's why we have test beds.

"Deciding where we live and work determines a great deal about our mobility and our use of time."

Markus Lienkamp

We're speaking today on April 5. The war in Ukraine is now in its sixth week. Germany's dependence on Russian oil and gas is the subject of much discussion. Do you expect to see an acceleration in the decarbonization of the transport industry?
Schreurs: I hope this terrible war will at least contribute to a quicker transition to renewables. In the energy sector, we're going to see a significant expansion of wind and solar energy, and battery research and development will be propelled forward. We can also expect big strides towards sector coupling, linking mobility to smart cities. How quickly we expand electromobility and the accompanying infrastructure will determine how quickly change will be realized in this dimension of mobility.

Lienkamp: OK, but remember that vehicles have a useful life of around 15 years. Even if, starting tomorrow, we decided to manufacture only electric cars, we would only be able to achieve a maximum change of about 7% per year. The only thing that can really help a mobility transition in the short term is a speed limit and fuel-saving incentives. People with company cars need to be the ones paying at the pump – that would have real impact, even if the company reimburses the cost.

Schreurs: You're right. Filling the car with gas is, relatively speaking, still far too cheap and is one reason the mobility transformation hasn't really progressed very far. There are many great concepts out there, but change has been far too slow.

Lienkamp: Everything we improve as engineers is immediately eaten up by the rebound effect, such as bigger cars and higher mileage.

Wulfhorst: A doctoral thesis on electromobility in our group showed that it isn't technology that will solve the CO_2 problem, but trade in emissions certificates that could have a real impact. With CO_2 as a key performance indicator, we could achieve the transformation without

“For the city of the future, we need to develop integrated mobility concepts that look at the overall picture.” Gebhard Wulfhorst

any subsidy programs for electric cars. That’s why it’s so important to keep the actual objectives in mind.

Lienkamp: We’re currently looking into the true costs of mobility, including all the various secondary impacts. As it turns out, some modes of transport are surprisingly expensive. Electric scooters, for example, are the most expensive form of transport because they are associated with so many accidents. Accidents, of course, have major economic impacts. We need to make such costs more transparent. The cheapest form of transport is walking – and that’s without even factoring in the positive effects on health. Factoring health into the equation makes walking and cycling actually have negative costs.

Schreurs: Until now, our thinking has been too sector-specific; we haven’t been focusing enough on interrelationships, such as the links between health, mobility, education, and so on. A holistic perspective would enable us to develop far better systems.

Wulfhorst: We really should be structuring our cities around walking. Munich has some good examples of walker and cycler friendly districts. In these areas, over half of all journeys are completed by bicycle or on foot. For the city of the future, we need to develop integrated mobility concepts that look at the overall picture. In our notes on local mobility, we’ve also emphasized that long waiting times at traffic lights make journey times far longer for pedestrians and cyclists. In Copenhagen, for example, the traffic lights turn green when a given number of cyclists are waiting at an intersection. Everything is possible; you just have to want it to happen.

Interview by Christine Rüth

MCube – Munich Cluster for the Future of Mobility in Metropolitan Regions

MCube brings together a unique network of actors from the fields of science, business, the public sector and society in the Munich region. Its goal is to develop sustainable solutions for mobility in metropolitan regions. The cluster program aims to establish Munich’s position as a pioneer of sustainable and transformative mobility innovations. Its current projects focus on three main fields of innovation: (1) electrifying and automating transport systems, (2) developing and integrating mobility options, and (3) networking and shaping mobility spaces. MCube is part of the Clusters4Future initiative operated by the Federal Ministry of Education and Research (BMBF). Launched in 2021, it will receive annual funding of up to €50 million for up to nine years. TUM coordinates the cluster, while TUM professors Gebhard Wulfhorst, Markus Lienkamp and Sebastian Pfotenhauer lead the MCube Strategy team.

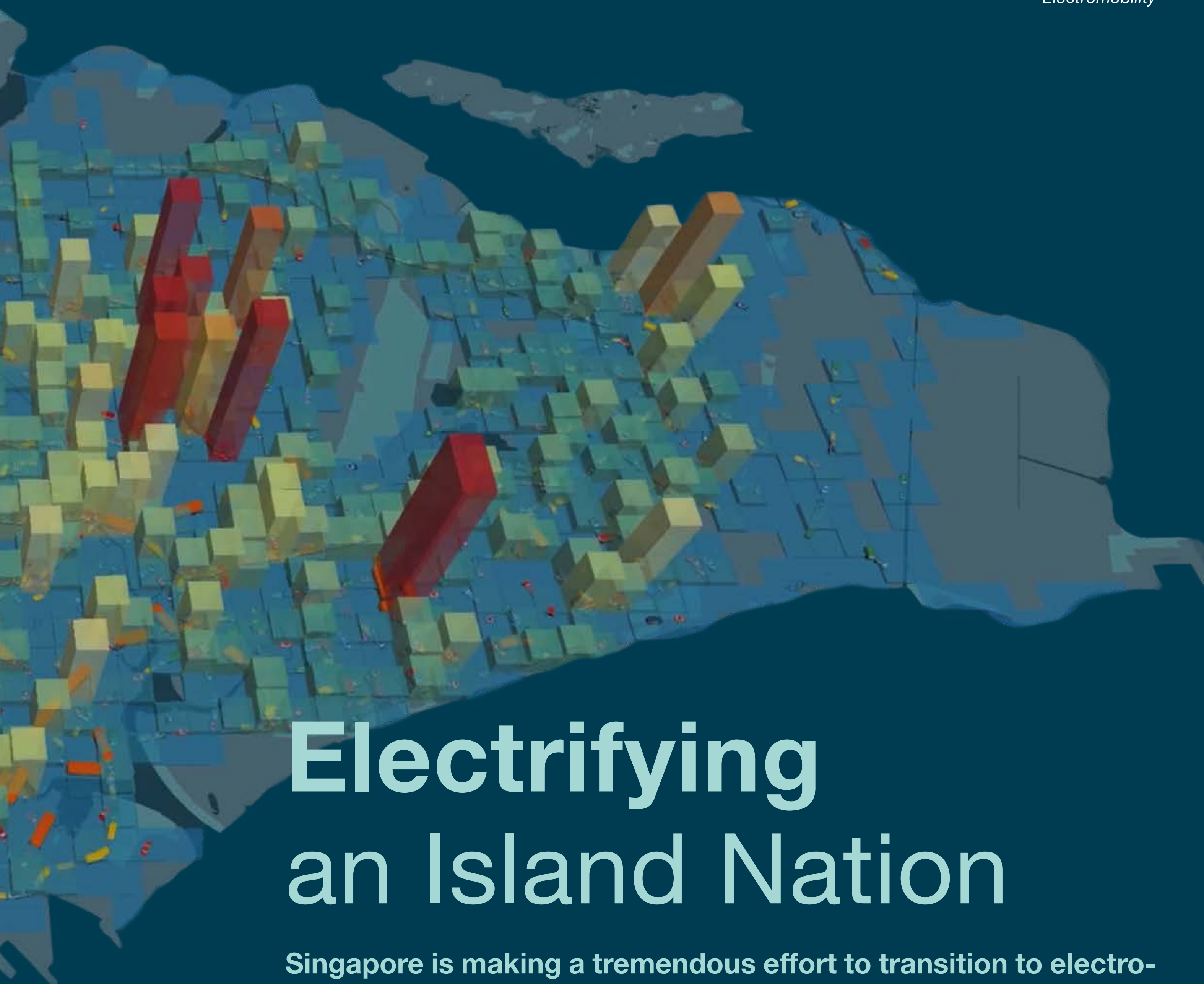
www.mcube-cluster.de

Researchers at TUMCREATE developed the software CityMoS, which is able to perform agent-based large-scale microscopic simulation of road traffic.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

Ein Inselstaat auf Strom

Singapur will künftig ganz auf Elektromobilität setzen, obwohl es in dem kleinen Stadtstaat kaum Platz für den Ausbau der regenerativen Energien oder neue Umspannwerke gibt. Mehr Ökostrom ist nur mit einem groß angelegten Umbau der Infrastruktur zu haben. Die Grundlagen für diesen Umbau haben Fachleute bei TUMCREATE, einem Gemeinschaftsprojekt der TUM und der Nanyang Technological University in Singapur, geschaffen. Unter der Leitung von Dr. Tobias Massier wurde das Simulationsprogramm MESMO entwickelt, mit dem sich durchspielen lässt, wie sich das Stromnetz verhält, wenn Elektroautos und vor allem Elektrobusse geladen werden. Ein anderes Team hat ergänzend das Simulationsprogramm CityMoS entwickelt, das den Straßenverkehr im Detail nachspielen kann. Damit lässt sich jedes Fahrzeug oder auch jede Ampelanlage in Singapur in Echtzeit simulieren. Im aktuellen Projekt SITEM werden MESMO und CityMoS verknüpft. Damit lässt sich fein aufgelöst analysieren, wie sich das Stromnetz im Konzert mit den Fahrzeugen verhält. □



Electrifying an Island Nation

Singapore is making a tremendous effort to transition to electromobility. Specialists from TUMCREATE, a collaborative project connecting TUM and Nanyang Technological University in Singapore, have examined how the associated infrastructure will have to expand to accommodate growing electricity demand. The simulation programs developed in the project demonstrate how electric cars, buses and taxis will interact and interoperate with the power grid in the future.

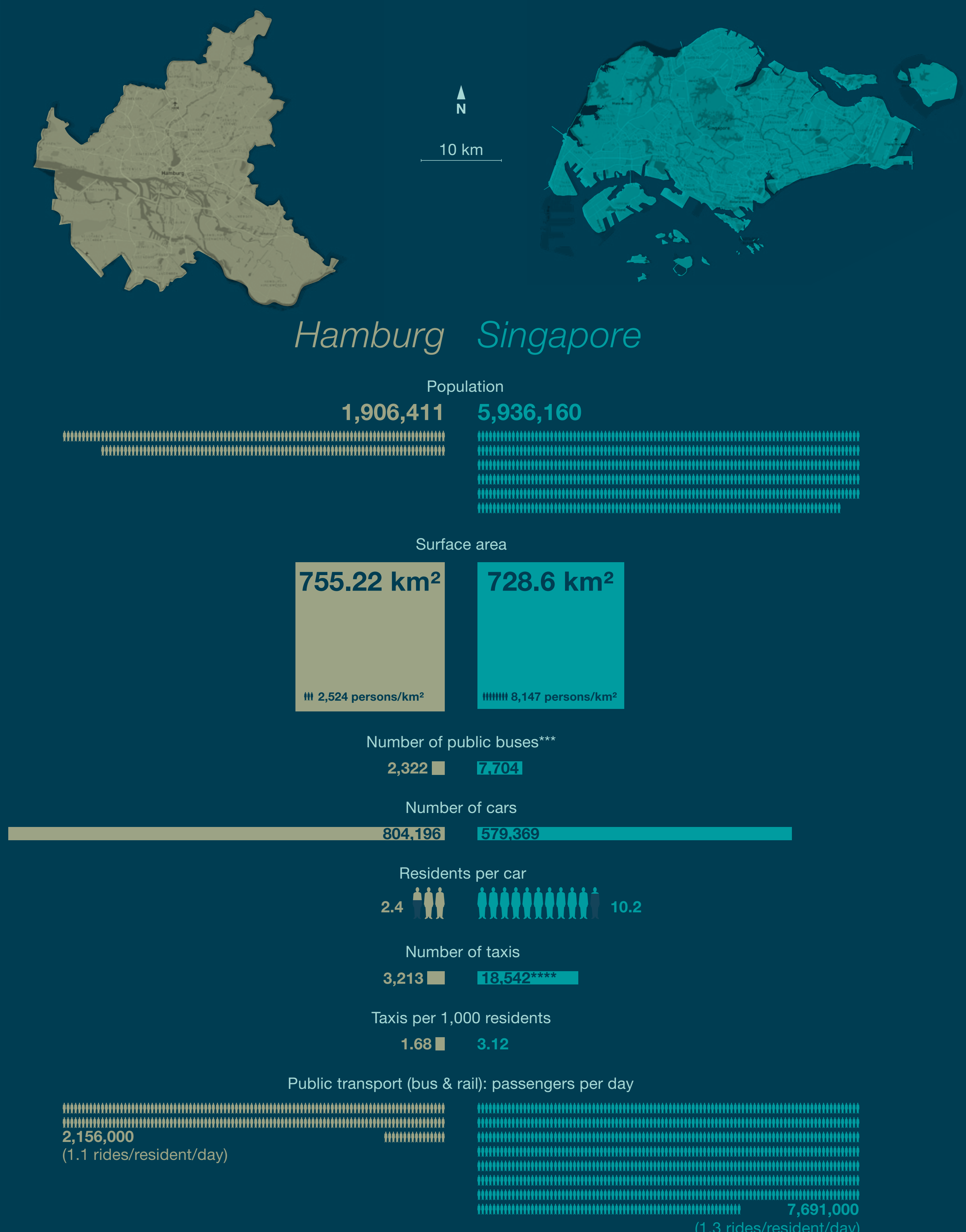
Link
www.tum-create.edu.sg/research/energy-and-power-systems-group www.tum-create.edu.sg/research/computational-modelling-research-department

Picture credit: TUMCREATE CityMoS

Singapore is renowned the world over. This Southeast Asian state is one of the largest trading hubs on the planet, boasts the world's second-largest container port, and is also a top tourist destination. Given these feats, it is an astonishingly small country. In fact, Singapore is only around two-thirds the size of the German state of Hamburg, yet it has over five million inhabitants. Space on the roads is at a premium on the main island, which stretches around 50 kilometers from east to west. In total, Singapore has around a million cars. In rush hour, around 6,000 public buses also roll around the island. On top of that are several thousand taxis. And, as almost all these vehicles run on gasoline or petrol, emissions of carbon dioxide and airborne pollutants are high. Thankfully, there is also an underground rail system, which the majority of Singaporeans use.

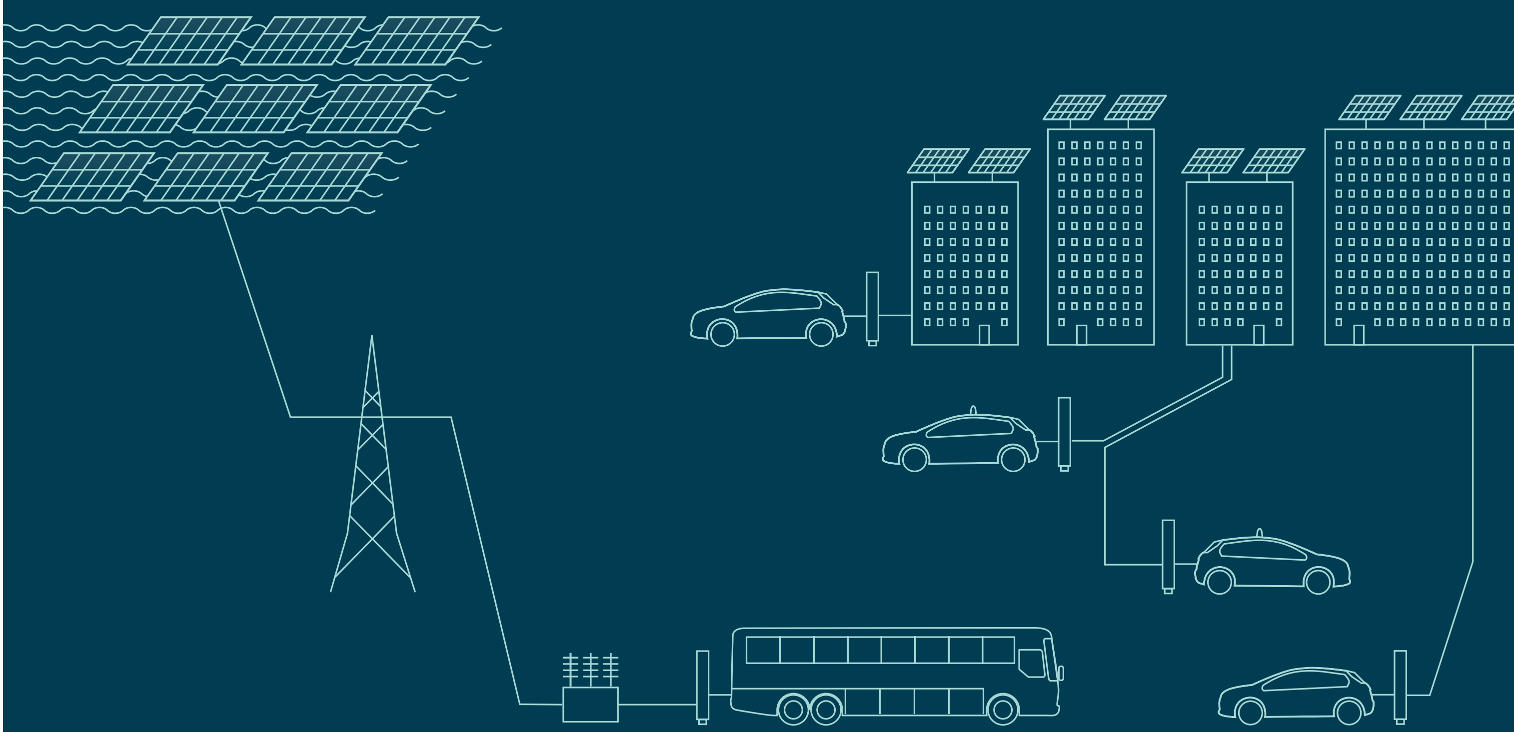
Target: 50% electric buses by 2030

The administration has therefore resolved to switch from vehicles with internal combustion engines to electric cars and buses in the coming years. By 2030, every other bus in the public transport system will be electric. This target presents a challenge for the small state at the southern tip of the Malay Peninsula, as there is limited space to expand regenerative energy systems or install new substations. The only way to increase the use of green energy is through large-scale infrastructural reorganization. Before embarking on this project, the city's administration wants to know exactly whether this transformation can succeed and, if so, how – without causing power cuts or impacting on quality of life. Specialists at TUMCREATE, a collaborative project connecting TUM and Nanyang Technological University in Singapore, have been working to put down the foundations for this immense retrofitting project in several projects over recent years. One of its research groups, the Energy and Power Systems Group, uses simulations to analyze in detail how the rise of electromobility will affect the power grid. "First, we took a close look at all road users," says Dr. Tobias Massier. "For example, we fitted taxis with GPS transmitters and collected all available data on car journeys to find out when cars are on the road, how they travel, and where they park." ▷



Sources: Statistisches Amt für Hamburg und Schleswig-Holstein, HVV Zahlenspiegel 2018; Singapore Land Transport Authority; worldometer May 2022
*** incl. school buses
**** excluding private hire vehicles

Graphics: ediundsepp



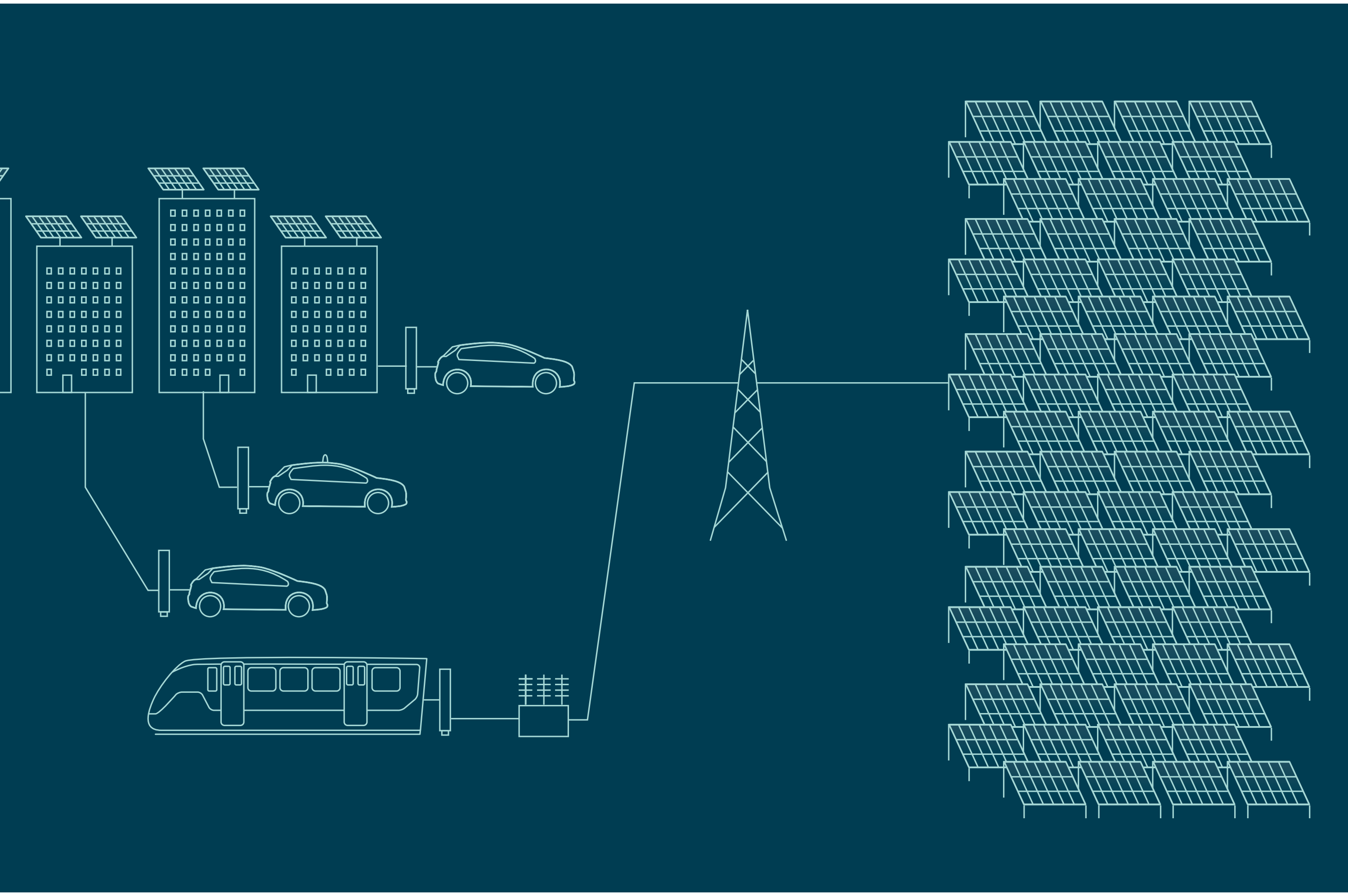
Where and when will electricity demand be highest? Where should solar photovoltaic systems be installed? The researchers analyze the behavior of the power grid to answer questions like these.

On average, private cars do not travel more than 50 kilometers per day, so electric versions would consume relatively little electricity. In the future, electric cars could be charged adequately in garages and parking structures beside office buildings and apartment blocks. Buses, however, pose a challenge: they operate for hours at a time, with little time for charging between journeys. In addition, there is very little space to install fast-charging stations beside bus stops in the heavily built-up urban area, as the huge batteries and high charging currents would require safety clearances to nearby buildings and thoroughfares. So, the electric buses of the future will have to be charged primarily at their final stops or at depots.

Understanding how the grid reacts

Over the last few years, Tobias Massier and his team have been developing MESMO, a simulation program that makes it possible to mimic exactly how the power grid will behave if high numbers of electric cars and buses need to be charged. Due to the high load requirements, it is likely that new transformers will be required in the vicinity of bus depots if the public bus network is to be fully electrified. Such insights are vital for the city administration and facilitate accurate, detailed planning. Colleagues of Tobias Massier have also developed a program called CityMoS, which can perform detailed simulations of road traffic. It can simulate every car, bus, taxi and traffic light in Singapore in real time, taking into account the current battery level and range of each and every vehicle.

In a current project called SITEM, which is supported by the Singapore city administration and led by the research enterprise A*Star, the TUMCREATE experts are working to connect MESMO and CityMoS. In the future, with the help of CityMoS, MESMO will be able to conduct high-resolution analyses of how the power grid behaves in concert with electric vehicles. Where should solar photovoltaic

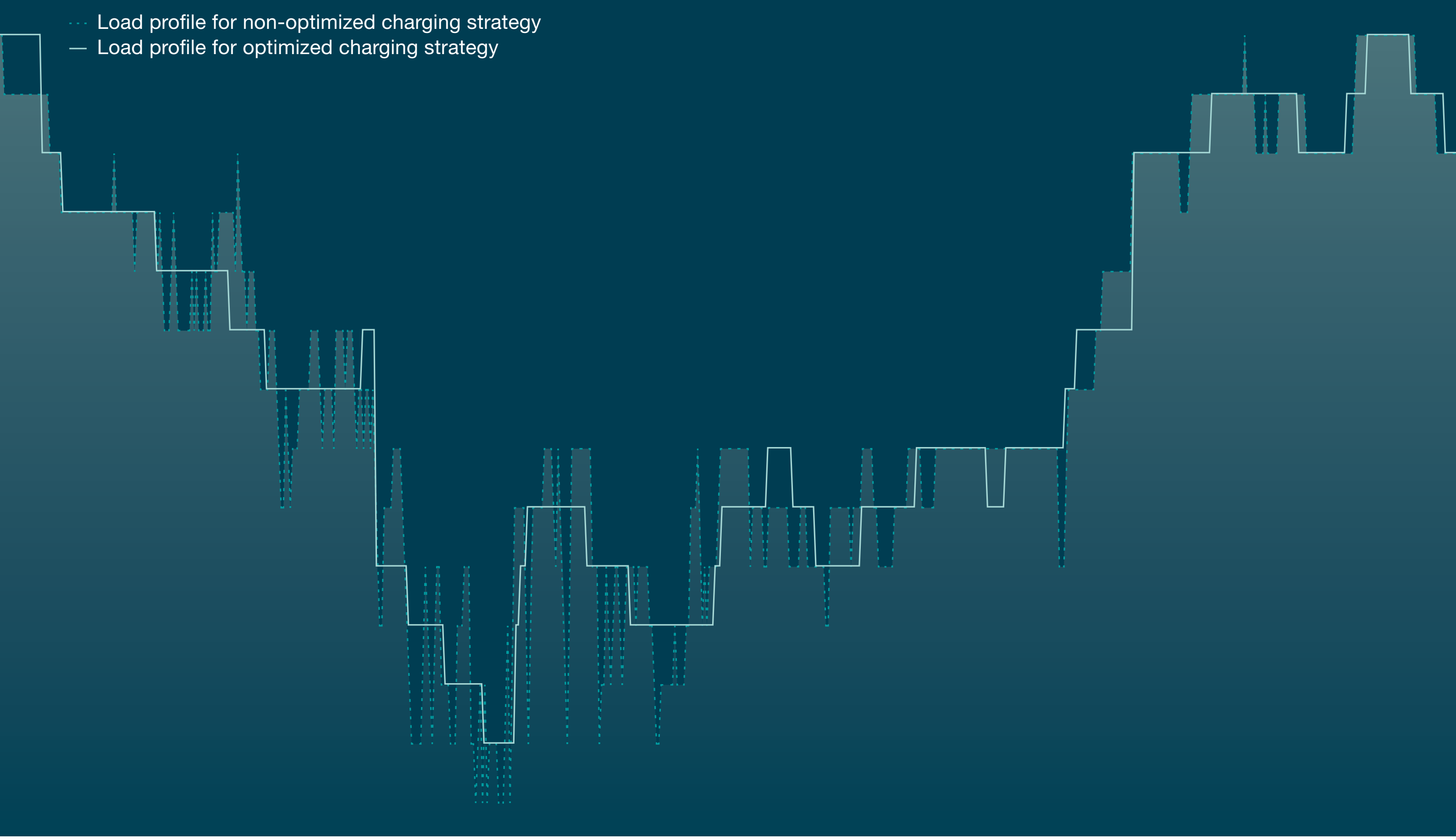


systems be installed on building façades and roofs? Where and when will demand for electricity be highest? These are the sorts of questions that SITEM will be able to answer for researchers and the local authorities. A particularly critical issue for power grids is load peaks – times when there is particularly high demand for electricity, such as first thing in the morning, when people switch on lights, turn on the radio and boil the kettle. To avoid exacerbating these peaks, it would be better to charge electric vehicles at times when demand for power is lower. Another concern in Singapore's hot, sultry climate is the thousands of air-conditioning systems in the city. Tobias Massier and his team have therefore examined the extent to which demand for electricity can be calibrated. One conceivable example, for instance, would be to reduce the output of air conditioning units during load peaks without allowing air conditioned rooms to become uncomfortably warm. That could also reduce the burden on the grid. ▷

"Over the years, the question of how to integrate electromobility into power grids became increasingly important."

Tobias Massier

Graphics: ediundsepp (source: TUM)



With a proper charging strategy, electric vehicles can help stabilize the power grid. The curves show the load profile during a typical day with fluctuating power supply from solar PV. Without optimization, the load profile reflects the high intermittency of solar PV supply. An optimized charging strategy for electric vehicles smoothes the load profile.

Electromobility entails high power demands

Singapore has long been striving to reduce the impact of road traffic. In 2018, for example, the administration placed a cap on the number of private cars allowed on the roads. Since then, citizens can only register a new private car when they take another off the road. However, such measures do not have a significant impact on emissions. Singapore will also have to do far more to combat the effects of climate change in the future. Tobias Massier explains that this is the reason behind the accelerated desire to move to electromobility. The city's plans also include expanding its photovoltaic systems. In addition to roof-based systems, Singapore started to install floating solar photovoltaic systems. However, the report 'Solar PV Roadmap' by the Solar Research Institute of Singapore has shown that, even if it were to expand its photovoltaic systems as far as possible, Singapore could only cover around 10% of its electricity demand using solar power. Consequently, it will have to source renewable energy generated by its neighbors, Indonesia and Malaysia. Plans for the first cable runs are currently being drawn up. For the project's cooperation partners in Singapore, such as A*Star and the city administration, the simulations conducted by TUMCREATE experts are an essential tool for estimating future electricity demand and imports. TUMCREATE is already planning a new project focusing on achieving a sustainable energy supply for Singapore.

TUM has been active in Singapore since 2010. Back then, its primary focus was perfecting automotive technology for electric cars, including for TUM's electric city car, the MUTE, under the leadership of Prof. Markus Lienkamp. "Over the years, the question of how to integrate electromobility into power grids became increasingly important," says Tobias Massier. "We are now reaping the rewards of these years of research. Singapore has everything it needs to embrace electromobility."

Tim Schröder

“Singapore has everything it needs to embrace electromobility.”

Tobias Massier

Dr.-Ing. Tobias Massier

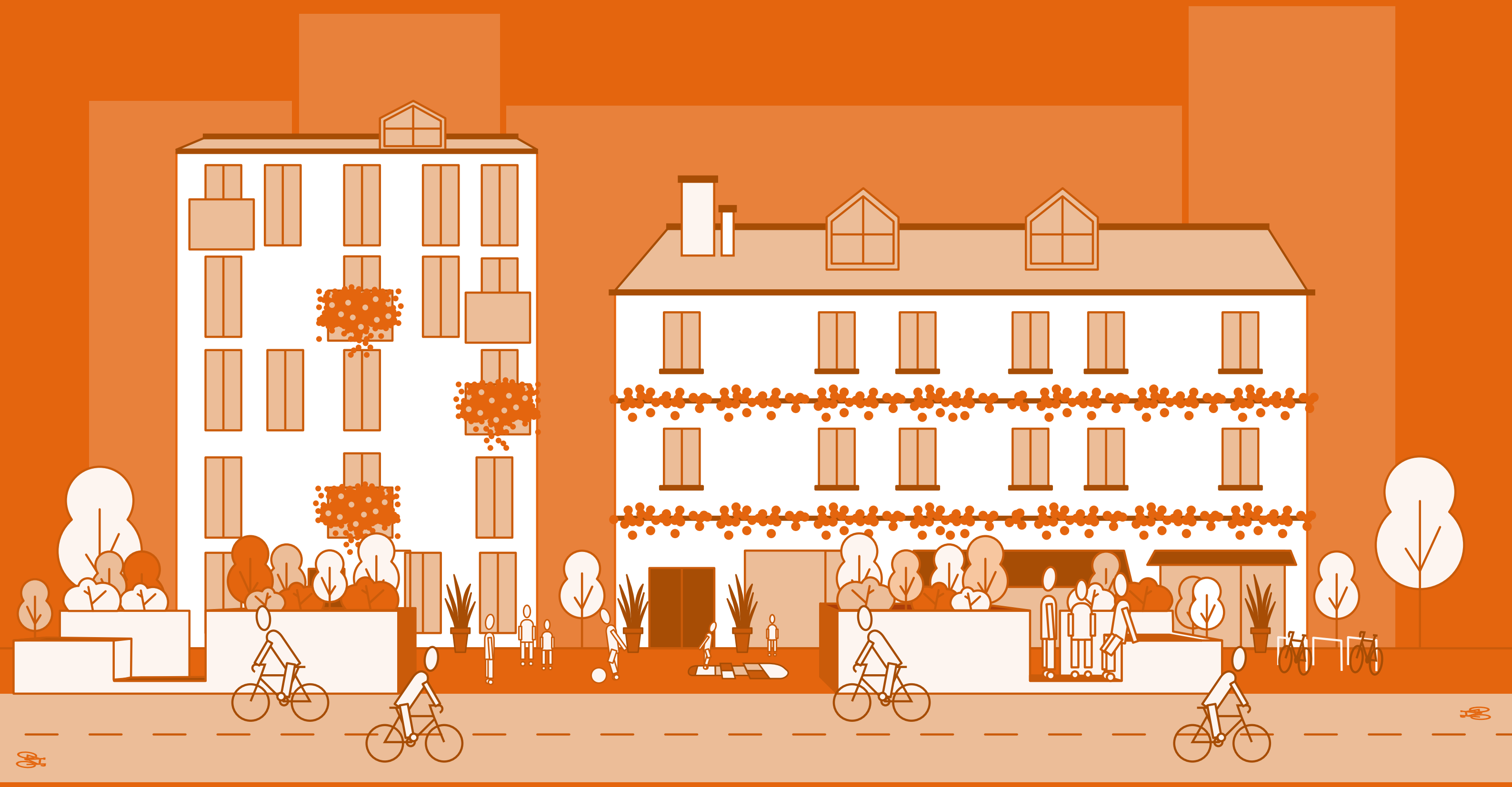
received his doctoral degree in electrical and computer engineering from TUM in 2010. His research focused on the structural analysis of analog integrated circuits. In 2009, he took over the position of program manager in order to establish a new Master’s program in Power Engineering (MSPE) at TUM. In 2013, he joined TUMCREATE as Principal Scientist and department head. His research focuses on integration of electric vehicles and renewable energies into the grid, as well as alternative energy supply options.

TUM CREATE – TUM’s innovation platform in Singapore

TUMCREATE was founded in 2010 to foster research collaborations between Singapore and TUM and is made up of over 100 scientists, researchers and engineers. As part of the NRF-funded Campus for Research Excellence And Technological Enterprise (CREATE), TUM has the opportunity to tap into Singaporean research funding and to partner with local institutions as well as leading global universities that are part of the CREATE campus. Researchers appreciate this unique opportunity for academic exchange and research ideas in Asia.

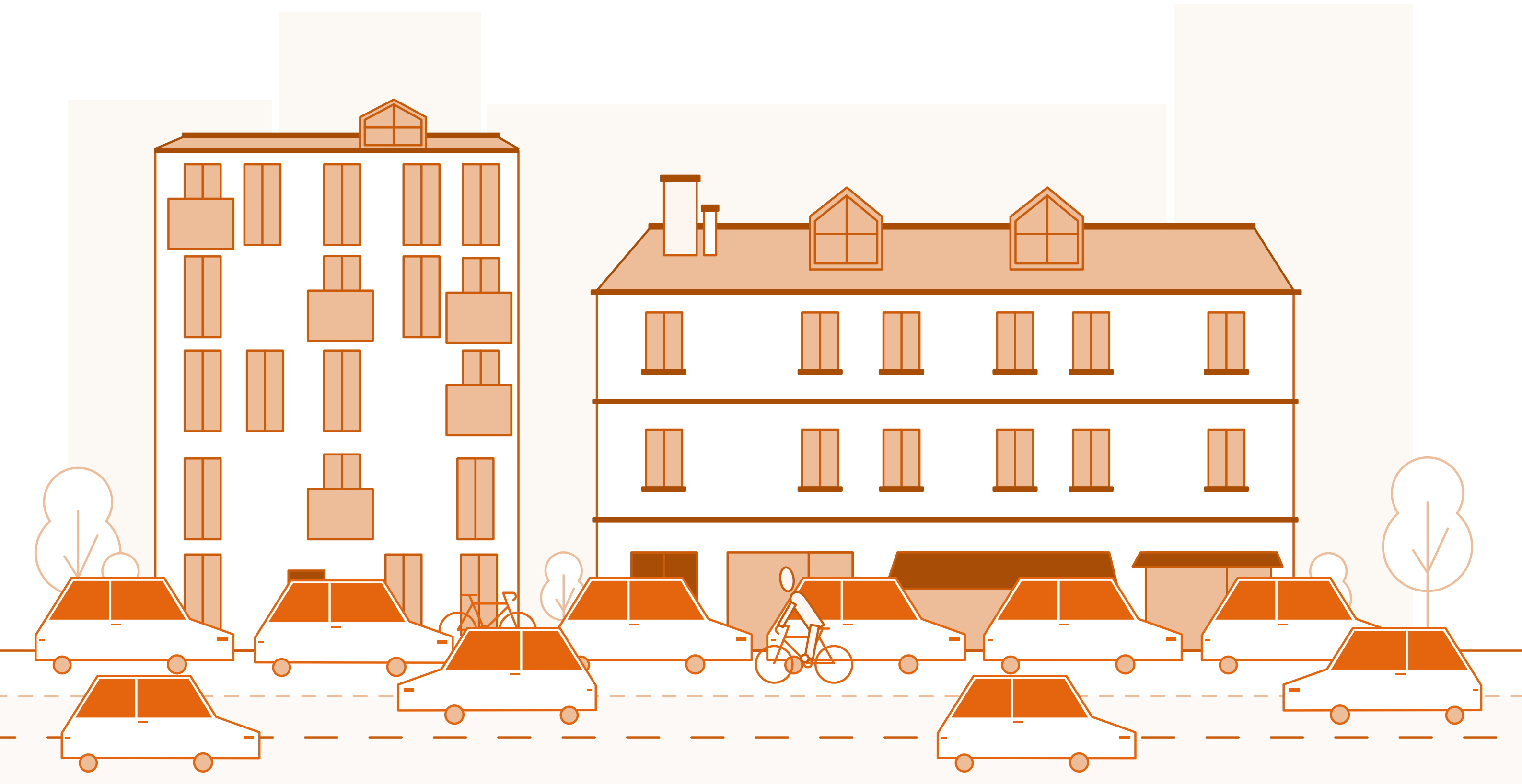
TUMCREATE has successfully managed various multidisciplinary projects within its mobility programs, in collaboration with academic and industry partners in Singapore. With its latest large-scale program Proteins4Singapore, TUMCREATE adds a complex, cutting-edge life science project to its portfolio.

Picture credit: TUMCREATE; Graphics: ediundsepp (source: TUM)



What Kind of City Do We Want to Live In?

Link
www.mos.ed.tum.de/sv



In an age of climate change, species extinction and resource scarcity, long-established spatial and traffic concepts are proving to be outdated and obsolete. So, why not try out the alternatives available to us, here and now? That's the idea behind street experiments. An interdisciplinary team at TUM's Chair of Urban Structure and Transport Planning is researching whether and to what extent this concept can be deployed in urban design and development.

Graphics: ediundsepp

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

In welcher Stadt wollen wir leben?

D

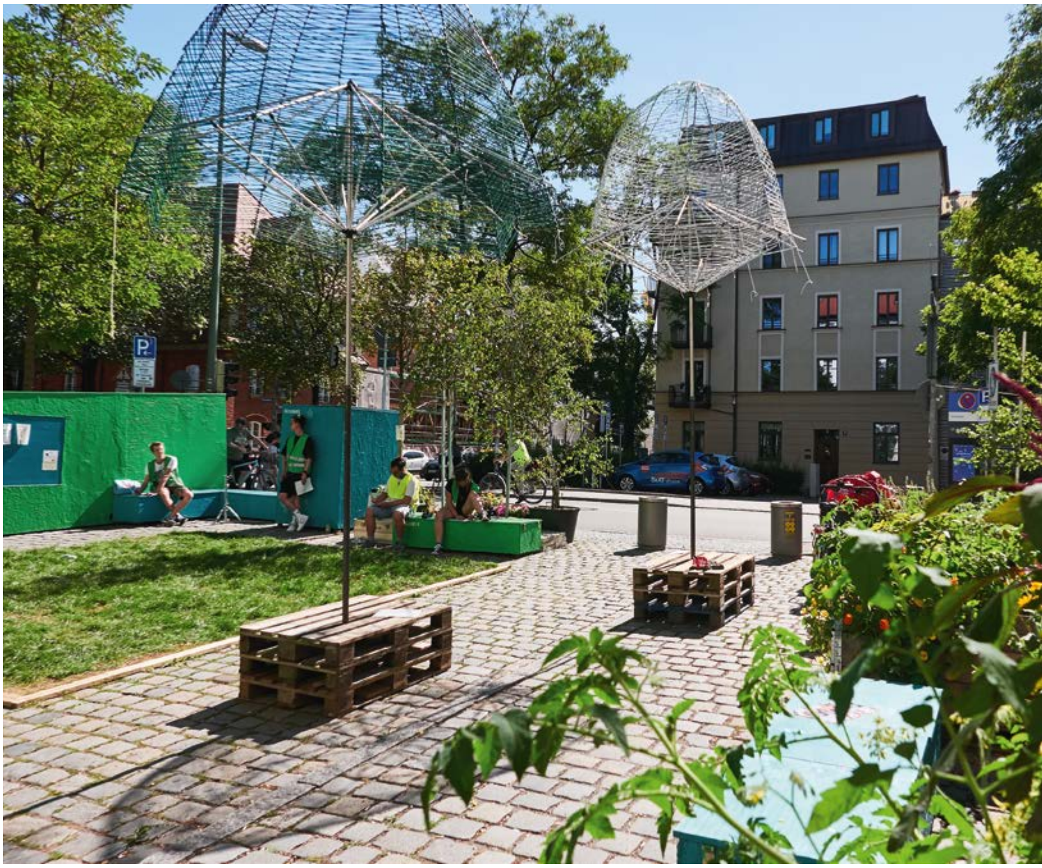
Wie wollen wir in Zukunft leben? Wie sollen unsere Städte aussehen, wie können wir den begrenzten öffentlichen Raum sinnvoll nutzen, wie uns fortbewegen? Viele Menschen spüren, dass es nicht mehr so weitergehen kann wie bisher. Klimawandel, Artenschwund und Ressourcenknappheit zwingen uns dazu, unseren Lebenswandel und damit auch unser Mobilitätsverhalten zu überdenken. Doch welche Alternativen sind sinnvoll und auch realisierbar? Dies herauszufinden, ist Ziel zahlreicher „street experiments“ überall auf der Welt. Sie öffnen für einen Moment ein Fenster in eine bessere Welt. Unter welchen Bedingungen sie zu bleibenden Transformationen beitragen und was wir von ihnen lernen können, untersucht ein interdisziplinäres Team am Lehrstuhl für Siedlungsstruktur und Verkehrsplanung der TUM. □

Munich. April 2022. Walking through the city's Schlachthof district, the sleek brick façade of the new Volkstheater instantly catches the eye. Situated directly opposite, Zenettiplatz offers another urban design highlight – though its significance might not be apparent upon first glance. The square is surrounded with plywood structures painted turquoise, inviting passers-by to sit and linger for a while. Large planters provide a base for an entire grove of trees, fringed with spring flowers and culinary herbs. There is a bulletin board peppered with notices advertising second-hand furniture and free training sessions at the nearby gym. A man flicks through the freely accessible book alcove, searching for new arrivals, his two exuberant sons having already snatched a comic book. "My neighbor's elderly mother loves coming here to chat to other local residents," says a woman who has left her electric car to charge at the mobility station over the road. She also confesses that she is grateful for the recently redeveloped "Piazza Zenetti".

Four years ago, this was nothing more than a parking lot for private vehicles. Its transformation into a place for people to meet, dedicated to local residents, started in the summer of 2018 by order of the City of Munich. The square was completely transformed as part of a research project called city2share, which involved local residents and was supported by a landscape architect. The parking spaces in the northern section made way for a place designed to allow people to relax and meet others, while the parking area in the southern section was converted into a mobility station with car and e-bike sharing services. The grand opening was attended by the mayor of Munich as well as representatives of the Federal Ministry for the Environment, the municipally owned transport company Münchner Verkehrsgesellschaft, and the project's industry partner, BMW. The whole project was originally conceived as an experiment and only scheduled to last six weeks. During this initial period, however, something clicked. A citizen's initiative formed and organized a series of street parties in the subsequent two summers along with activities focused on the new "piazza", which ultimately led to the change being made permanent.

Pandemic emboldens citizens with desire for change

The "Piazza Zenetti" is a prime example of successful transformation of the public realm. It is also far from an isolated case, from Milan to New York, Barcelona to Bo-



gota, urban residents are turning to ciclovías, “play streets” or “summer streets” to enable their vision of a better world to run free. Although no two projects are alike, they are all connected by a shared longing for change. People sense that things cannot continue as they have been to date. Climate change, environmental pollution, species extinction, resource scarcity and, of course, the coronavirus pandemic have all forced us to rethink our way of life, including our mobility behavior. But what alternatives exist that are both reasonable and practically feasible? Numerous street experiments are underway around the world with the aim of finding out. From an academic perspective, street experiments are “deliberate, time-limited changes in street use, regulation and/or form with the aim of researching systemic changes in urban mobility”. The project at Munich’s Zenettiplatz is just one example.

“The coronavirus pandemic was a veritable booster for these initiatives,” highlights Gebhard Wulfhorst, who leads the Chair of Urban Structure and Transport Planning at TUM. “It suddenly sparked a great willingness in society to challenge and question many things, to give new ▷

Global connections – participate!

Street experiments depend on an exchange of experiences. Ana Rivas and Benjamin Büttner, supported by the TUM Institute for LifeLong Learning and the EIT Innovation Community in Urban Mobility, provide an introduction to the purpose and nature of street experiments in a massive open online course (MOOC). The Street Experiments Tool (SET) offers a brief guide to planning and evaluating street experiments. Participants can further their expertise in a two-week bi-national summer school in Munich and Rotterdam.

Visit www.streetexperiments.com to learn more!

MOOC Street Experiments for Sustainable and Resilient Cities: https://www.coursera.org/learn/streetexperiments

Installation: Raumzeug - Atelier für Landschaftsarchitektur, Felix Lüdicke (TUM); Picture credit: Johann-Christian Hannemann

“Piazza Zenetti” is one of several street experiments in Munich. The installation was designed and built by landscape architects who also work at TUM’s Chair of Landscape Architecture and Public Space (Prof. Regine Keller). “Piazza Zenetti” is the case study in Felix Lüdicke’s dissertation about street experiments in that Chair.

What makes a street experiment successful? Ana Rivas has examined:

150

street experiments

38

countries

3

each in Munich and Amsterdam

Acceptance, communication and citizen participation

are the criteria that determine the success of street experiments

things a try, and even to buy into very strict restrictions at many levels for temporary periods. The pandemic has also had an extraordinarily positive impact on the willingness and courage to pursue change." For many years, people have been resigned to the fact that streets – particularly in urban areas – are dominated by motor vehicles, whether parked or driving. "But we have been forced to reflect and realize that streets are not primarily made for cars but for people! Streets are part of the public realm where we meet others and chat with neighbors, sit in cafés and go about our daily business. Once you understand that, it can be better incorporated and implemented in planning processes," emphasizes Wulfhorst's doctoral student, Ana Rivas.

"We have been forced to reflect and realize that streets are not primarily made for cars but for people!"

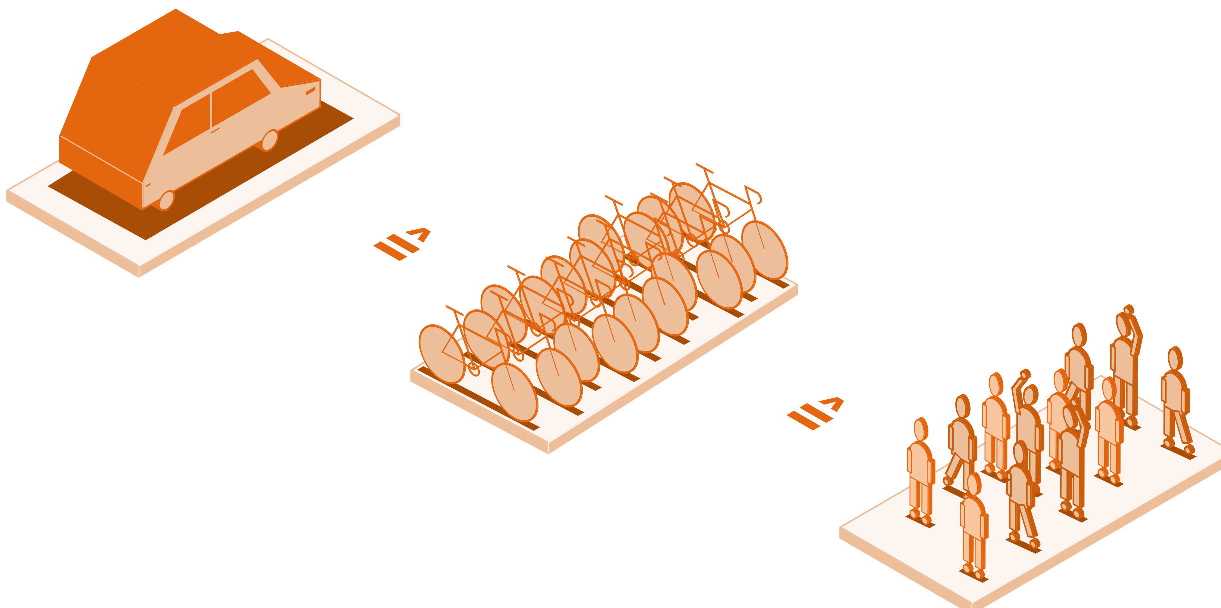
Ana Rivas

Public space is a hotly contested resource

In the course of her dissertation, architectural researcher Rivas gathered data on around 150 street experiments in 38 countries, analyzing six projects in Amsterdam and Munich as case studies based on her own catalog of criteria. Rivas wanted to find out the conditions under which time-limited initiatives lead to lasting change at different levels, including individuals' mobility behavior, urban planning, building design and engagement with different interest groups.

So, what did she find? "There are three criteria that determine the success of a street experiment, namely acceptance, communication and citizen participation. This means that those who are directly affected should be involved as closely as possible in the concept and execution of a project to gain their commitment to the cause. At the same time, the entire process must be coordinated with all stakeholders on an ongoing basis and also communicated to the outside world. Finally, it is very important to have local authorities on board."

Urban transformation is not an easy task, as public space is a valuable resource and – due to its limited nature, especially in major cities – is hotly contested. "The challenge here is to find a balance between the interests of different groups: people who drive and those who cycle, others who get about on foot, deliver goods, visit local bars or want spaces to play in," explains Gebhard Wulfhorst. "There are plenty of potential technical solutions, from new drive systems in electromobility to autonomous driving to sharing and shuttle models with bicycles, scooters, buses and taxis. Yet, all these concepts can only achieve success if their products and services can be integrated into the public realm – otherwise, bicycles will end up lying around on footpaths and that will annoy



Space-consuming car: The area of one car parking space (approx. 12 m^2) has room for between 6 and 20 parked bicycles or as many pedestrians.

Graphics: ediundsepp (source: TUM)

everyone. Innovations need to be integrated as a common, sociocultural construct, which means developing, exploring, considering and trialing them together."
Street experiments, as shown by Ana Rivas' research, can make an important contribution to this process. "This idea of bringing different stakeholders together, which we have developed with our partners in Amsterdam and Milan, is something we now want to pursue more intensively in Munich," explains Wulfhorst. Established in the fall of 2021, the Munich Cluster for the Future of Mobility in Metropolitan Regions (or MCube for short) provides a framework for this research and is part of a new funding program established by the Federal Ministry of Education and Research (BMBF). The vision behind MCube is to establish Munich's position as a pioneer of sustainable and transformative mobility innovations. One of the cluster's lighthouse projects aims to create low-traffic neighborhoods through the use of multi-modal transportation options. "In that project, working together with the Chair for Urban Design, the City of Munich and private partners, we want to combine alternative mobility systems with new design concepts for the public realm. It is exactly these ideas that we know from successful street experiments and now wish to put into practice."

■ *Monika Offenberger*

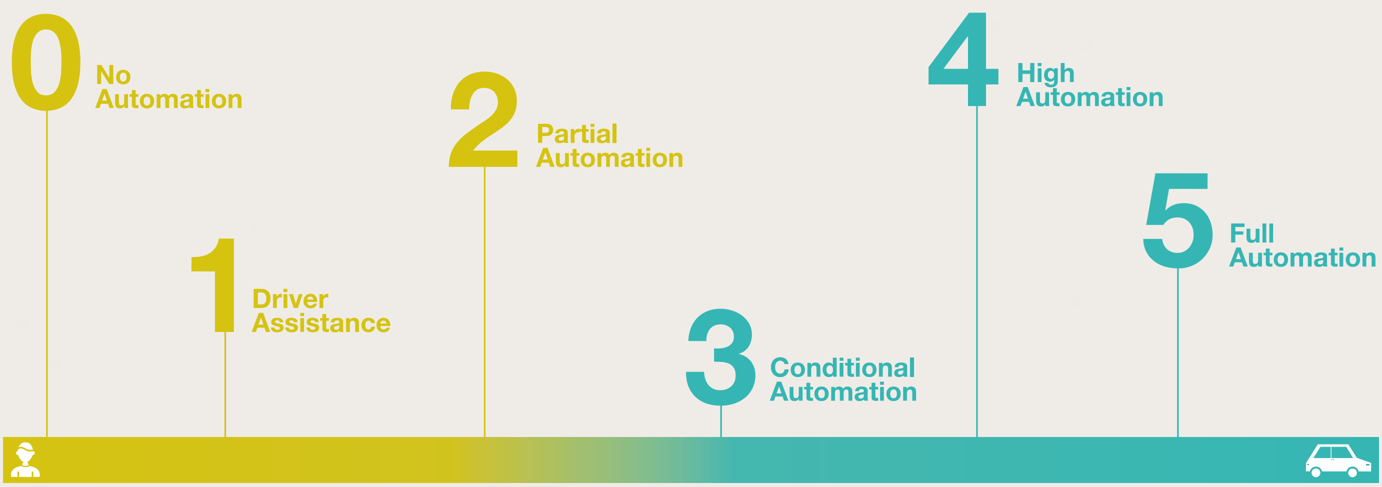
European partners

The European Institute of Innovation and Technology (EIT) was set up in 2008 as an independent body of the European Union, tasked with delivering innovation across Europe. The EIT brings together leading companies, educational institutions and research institutes in order to form dynamic cross-border partnerships. The resulting Innovation Communities are dedicated to the interdisciplinary search for solutions to the major global challenges of our time. TUM is involved in the following EIT Innovation Communities: Health, Food, InnoEnergy, Digital, Climate – and, last but not least, Urban Mobility. TUM serves as a strategic partner to EIT, committed to promoting sustainable urban development through revised urban mobility strategies.

Autonomous Driving

Autonomous driving offers great potential for smart mobility. The technology promises to make future mobility systems safer, cleaner and more cost-effective.

Autonomous vehicles drive without human intervention from A to B in road traffic. They perceive their surroundings with the help of various sensors, evaluate the data and use algorithms to calculate appropriate responses. In the future, autonomous vehicles will also be networked and communicate with each other and with the infrastructure to exchange information, for example, on traffic flow, accidents, weather conditions or road works.



The Society of Automotive Engineers (SAE) defines six levels of driving automation, which describe the distribution of tasks and responsibility between vehicle and driver. The levels range from no driving automation at all (Level 0) to full driving automation (Level 5). Vehicles labeled with levels 0 to 3 are equipped with various combinations of driver support features (for example automatic emergency braking or adaptive cruise control). Level 3 marks the entrance of automated driving features such as traffic jam chauffeur. A level 5 vehicle can drive under all conditions without a human driver present. The full SAE J3016 taxonomy can be found at www.sae.org.

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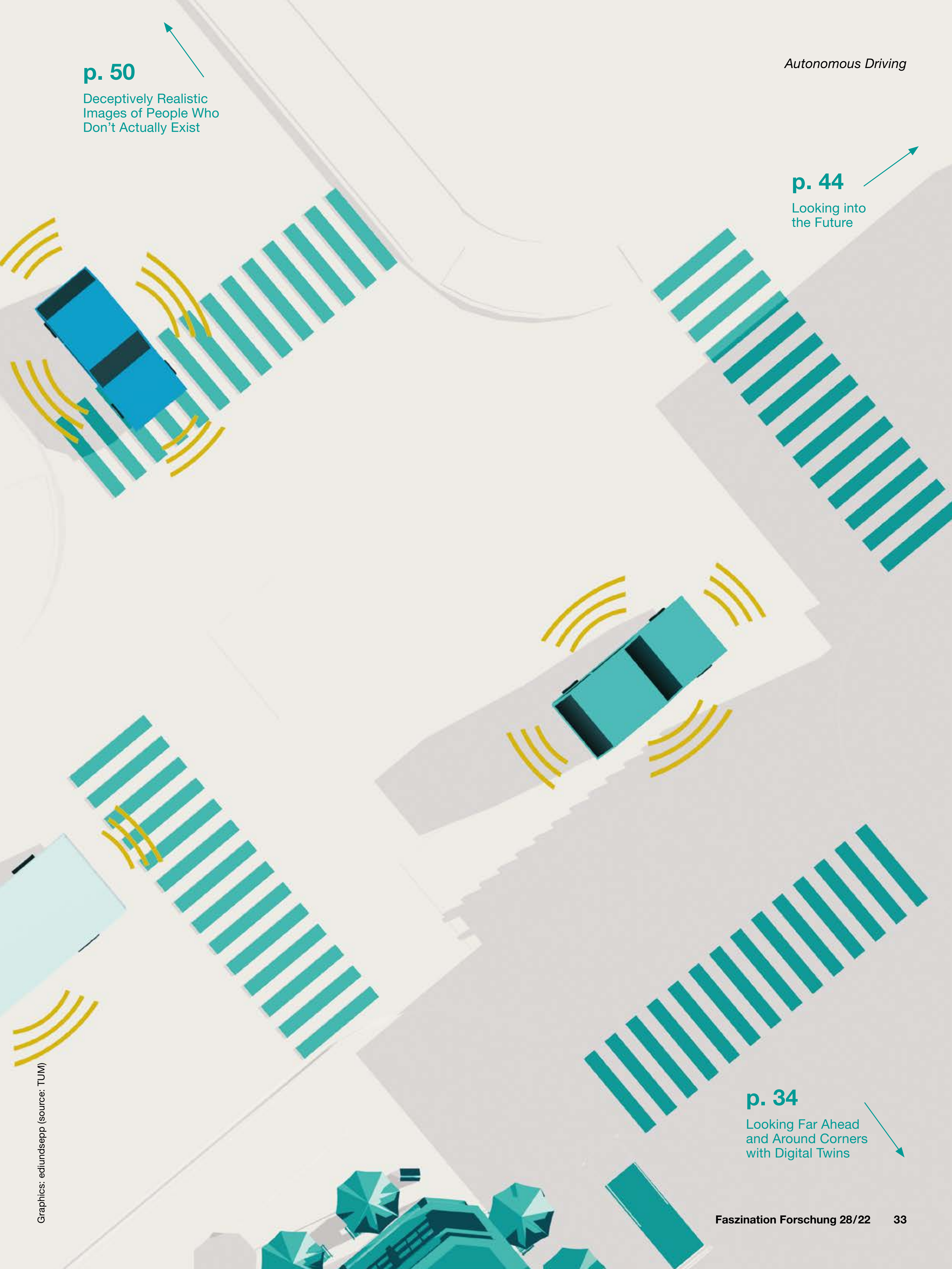
Automated Driving Will Require a New Traffic Culture



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Deceptively Realistic Images of People Who Don’t Actually Exist

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Looking into the Future

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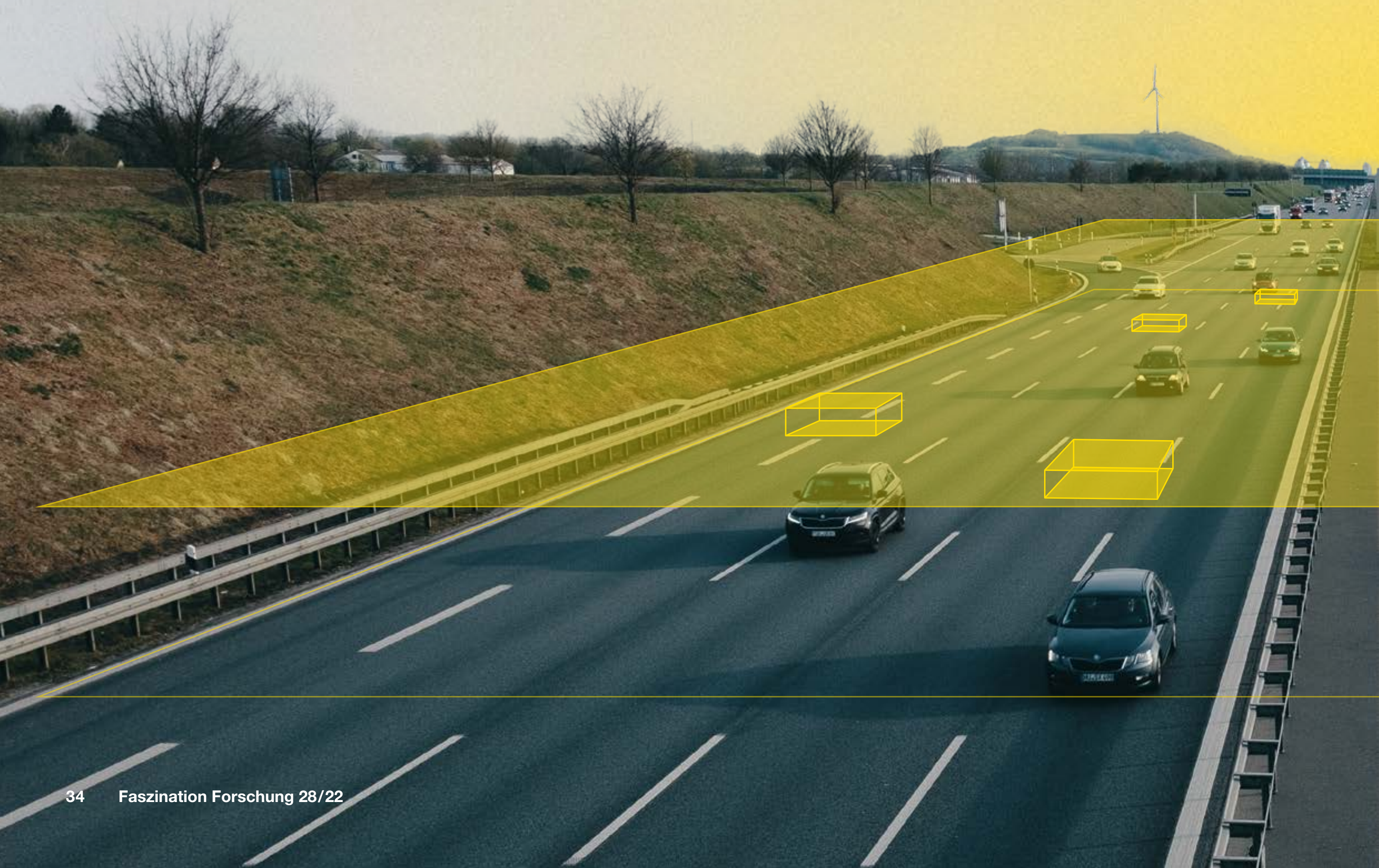
Looking Far Ahead and Around Corners with Digital Twins

Graphics: ediundsepp (source: TUM)

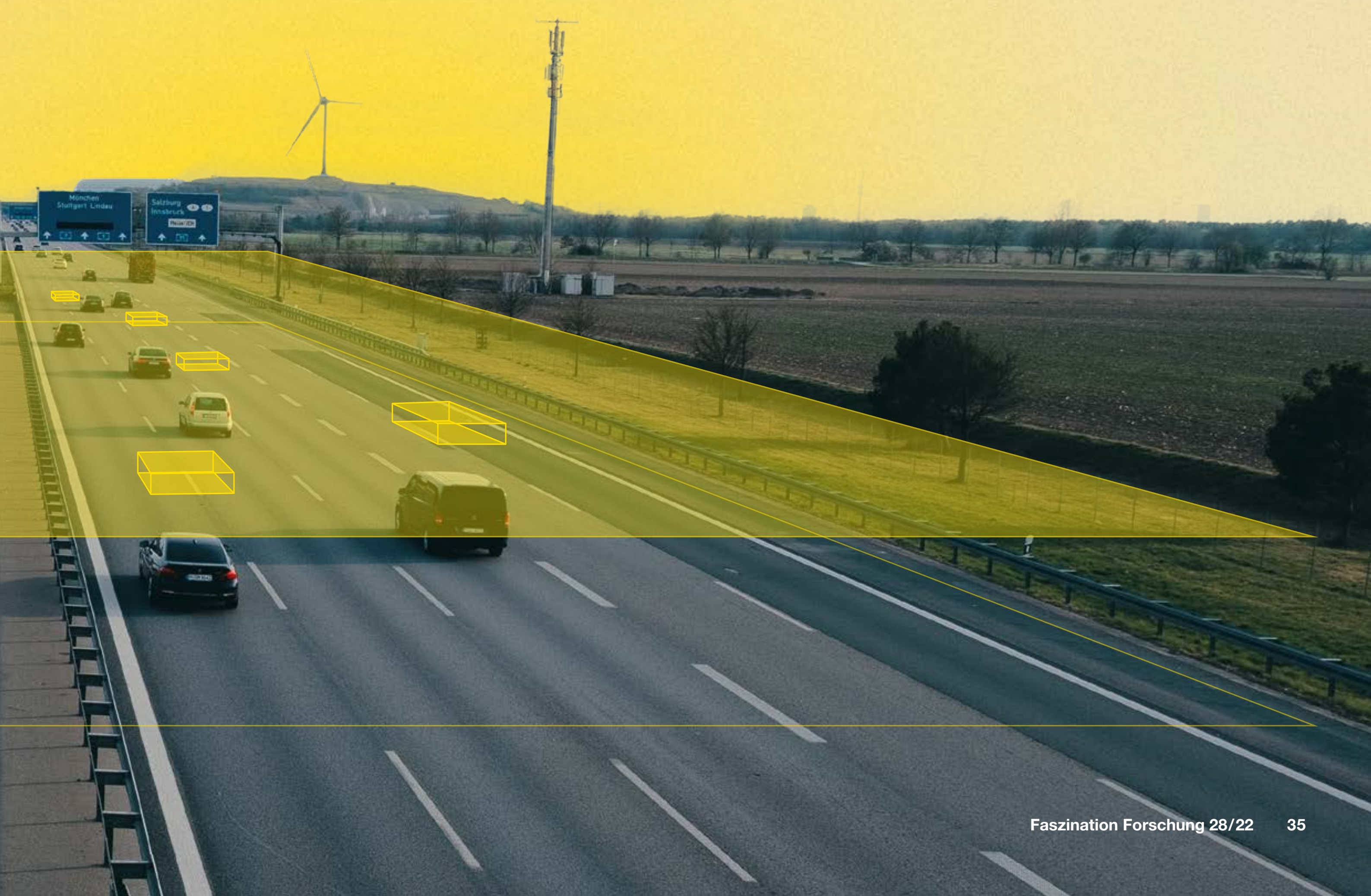
Looking Far Ahead and Around Corners with **Digital Twins**

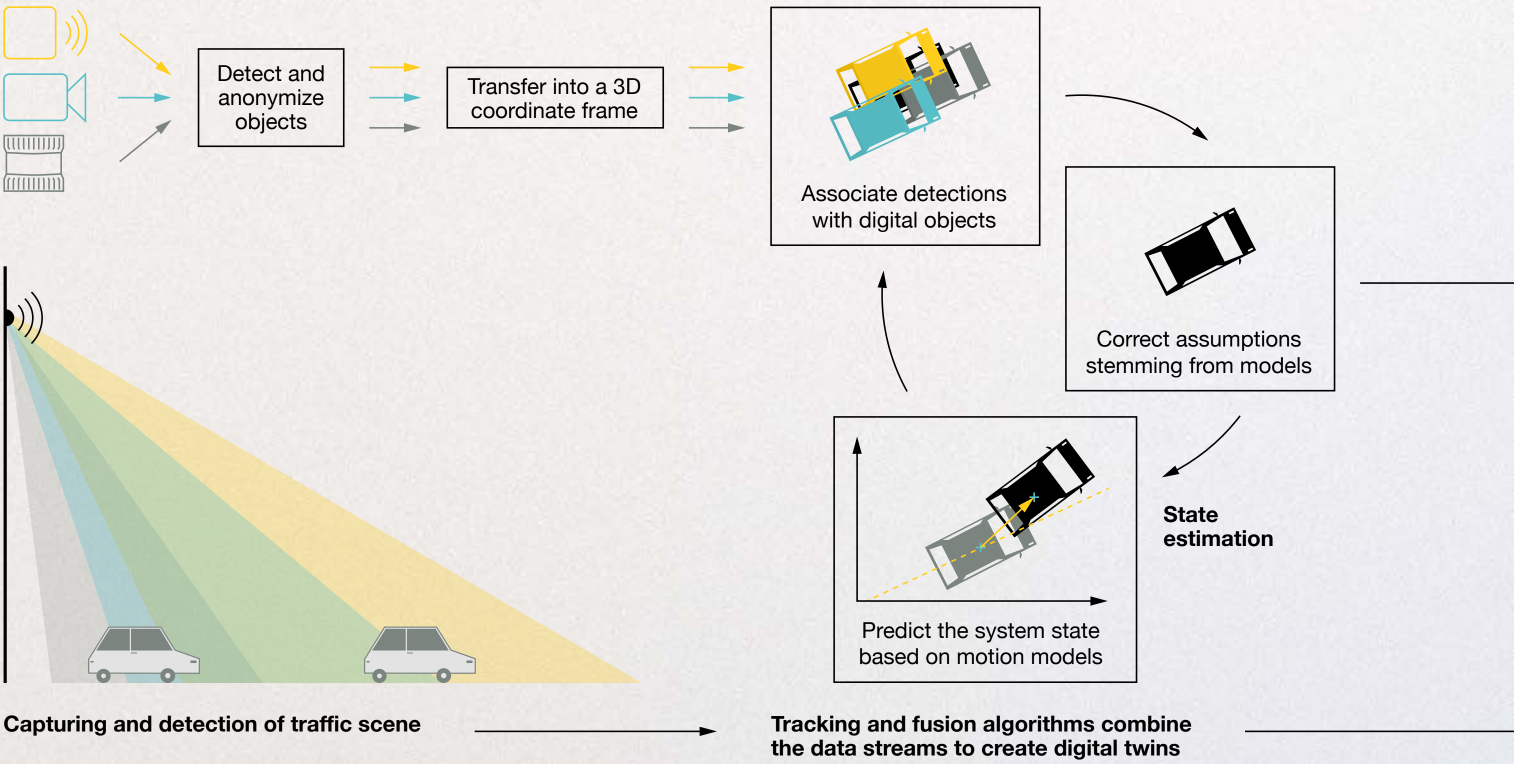
Link
www.ce.cit.tum.de/air/home www.innovation-mobility.com



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

How can we control and regulate traffic to improve safety and convenience while also making the best possible use of existing infrastructure? In the Providentia++ project, Professor Alois Knoll and his team have developed a digital twin using data from roadside sensors to depict the current traffic situation in a machine-readable form in real time.





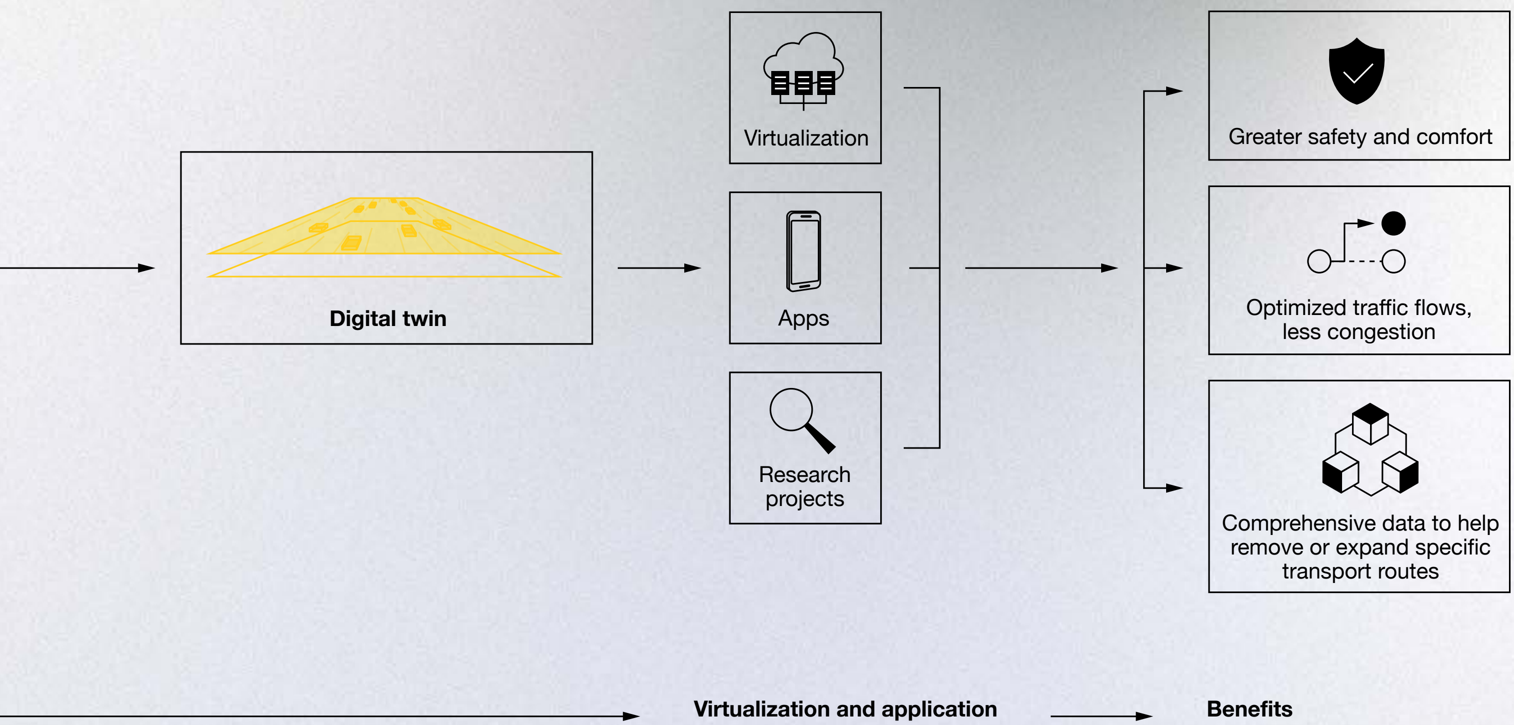
Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

Um die Ecke schauen mit dem digitalen Zwilling

D

Im Projekt Providentia++ (Proaktive Videobasierte Nutzung von Telekommunikationstechnologien in innovativen Autoverkehr-Szenarien), das vom Bundesministerium für Digitales und Verkehr gefördert wird, entwickeln Prof. Alois Knoll und sein Team am Lehrstuhl für Robotik, Künstliche Intelligenz und Echtzeitsysteme der TUM ein System zur Verkehrsüberwachung in Echtzeit. „Mithilfe unterschiedlicher Sensoren beobachten wir alle Verkehrsteilnehmerinnen und Verkehrsteilnehmer und übertragen deren Position und Geschwindigkeit in einen digitalen Zwilling, welcher das Geschehen virtuell abbildet. So sind wir in der Lage, nicht nur aktuelle Staus und Gefahrensituationen rechtzeitig zu erkennen, sondern sogar in die Zukunft hochzurechnen, wann eine Gefährdung oder ein Stau entstehen könnte“, so Knoll. An dem Projekt nehmen zahlreiche Firmen teil, Knoll hat die Konsortialleitung übernommen. □

While at first glance appearing deceptively unspectacular, this project could well bring about one of the most significant steps forward in the history of road traffic. All there is to catch the eye are a few cameras and small boxes attached to overhead gantry signs over a five-lane carriageway in Garching-Hochbrück, just north of Munich, along with a few radio masts. And yet, this project has its sights set on nothing less than a revolution, as researchers strive to pave the way for the digitalization of road traffic. Just as Google Maps has digitalized road maps, Wikipedia has taken the sum of the world's knowledge online, and Zoom has made conferences digital, Providentia++ can depict current road traffic – that is, the position and speed of all road users, including cyclists and pedestrians – in a digital form, making this data available to all. This real-time view offers wide-ranging advantages, from prompt hazard warnings and the ability to avoid traffic jams, to distributing traffic flows with optimal efficiency.



Graphics: ediundsepp (source: TUM)

A win-win-win situation

Research projects rarely feature such a close connection between theory and practical application as Providentia. In early 2020, Prof. Alois Knoll and his team at the Chair of Robotics, Artificial Intelligence and Real-time Systems at TUM took over consortium leadership for the follow-up project Providentia++ from fortiss, a research institute of the Free State of Bavaria. “The technology we develop delivers benefits in several respects,” he says. “It provides greater safety and convenience for road users; it helps cities, municipalities and motorway operators to optimize traffic flows, and it gives urban planners data they can use to improve transport infrastructure.” At the same time, Providentia++ (an abbreviation of its German name, which translates to Proactive Video-based Use of Telecommunications Technologies in Innovative Traffic Scenarios) operates at the cutting-edge of research, fusing together data streams from various different sensors, using artificial intelligence to support analysis, networking transmission points and, for the first time, making real-time data on the transport scene available to download. Numerous companies are involved in the €17 million project, which (like its predecessor project Providentia) is supported by the Federal Ministry for Digital and Transport with around €11 million of funding.

The eponymous goddess, who adorned the reverse side of coins in Ancient Rome, was the personification of divine foresight and the emperor’s care for his citizens. “Likewise, Providentia++ preempts problems by giving us a complete and comprehensive picture of current traffic in real time using a digital twin,” the professor explains. “Various sensors enable us to observe all road users and transfer their position and speed into a digital table, which – similar to a computer game – virtually depicts what is going on. As a result, we are in a position not only to promptly identify current traffic jams and hazardous situations, but also to predict when a hazard or traffic jam might arise in future.” Corresponding notifications can then be sent to drivers via mobile telephones, for example, when they have downloaded the Providentia app. Another option would be to display messages on sat-nav systems. ▷

Sensors on road bridges

In the predecessor project, Providentia, which ran from 2017 to 2020, the researchers initially fitted cameras and radars to two sign gantries on the A9 autobahn north of Munich. In the follow-up project, Providentia++, they have expanded to what is now a 3.5 kilometer long test section, continuing along the B471 federal highway as it branches off from the A9 and leads into a built-up area. The institute's driving simulator in Hochbrück allows users to experience the digital twin live. “We can cruise along with the traffic on the A9,” says doctoral student Walter Zimmer. “But we can also monitor the current situation at the junction in Hochbrück.” Even a domestic PC is enough to observe traffic flows live, as they happen. In addition, the Chair's team makes the A9 datasets available for commercial and scientific purposes, free of charge.

At present, the team has 75 sensors in use, from cameras to radar and lidar systems, constantly capturing data about the current traffic situation. “We very intentionally combine different sensors,” says Alois Knoll. “It's sort of like the human senses: sight and sound complement each other to form an overall picture. That being said, combining all of the different data is a considerable technical challenge.”

Unsurprisingly, the processing involves large volumes of data: a single area-scan camera, for example, generates around 400 megabits of data per second, or about 4 terabytes every day. “First, high-performance computers deployed on-site reduce this volume of data down to the essentials,” explains doctoral student Christian Creß, outlining the process. “This means that, ultimately, we only receive a few bytes for each traffic object. It's only by cutting the data down in this way that we can actually transfer data in real time.” This is achieved using directional radio relays. Creß also mentions the challenges that they had to overcome in the initial phase of the project. “Gantry vibrations and poor weather conditions impair data quality significantly,” he says. “We had to adapt to that.”

The researchers dispel any concerns that Providentia++ could lead to blanket monitoring of road users by highlighting that no personal data is ever collected. Each object is anonymized in the first step of the process, with license plates and faces made unrecognizable. In subsequent steps, the data processing focuses solely on the anonymized positional data. The researchers have also put measures in place to make the transmission highly secure.

▷

3.5

kilometer long test section

75

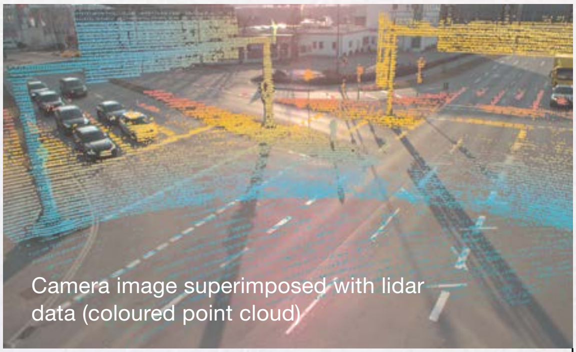
sensors in use

20

gigabits per second of raw data

Sensors at the signal systems record traffic events. A digital twin is constructed in real time. On this basis, traffic light phases can be controlled automatically and adaptively, for example, or road users can be warned of dangers.

Picture credit: Walter Zimmer (TUM, 2022);
Graphics: turbosquid, ediundsepp (source: TUM)



Camera image superimposed with lidar data (coloured point cloud)

Sensors and their advantages

Area-scan camera: Records all vehicles and pedestrians in a visible area

Radar: Detects road users by using reflected radio waves, recording their distance and speed; also works well in the dark and in foggy or rainy conditions, good depth resolution

Lidar: Detects road users by using reflected laser beams, recording their distance; works well in darkness, high precision

360° camera: Provides an overview

Event-based camera: Only reacts when something changes in the field of vision. Saves energy and reduces the volume of data generated as it only saves moving images

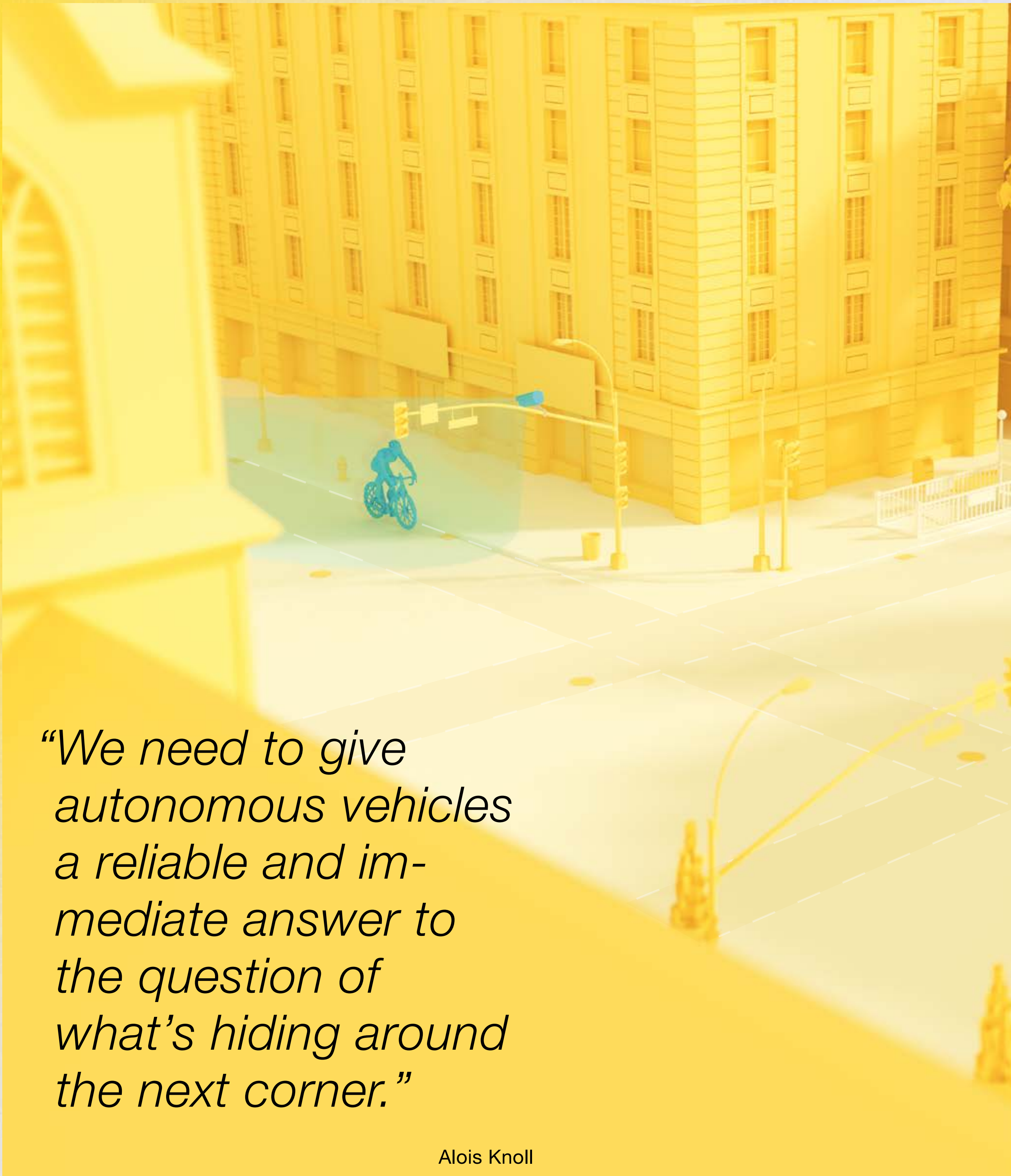
Top: Cameras, lidar and radar sensors mounted on road bridges register the traffic scene. Middle: Project lead Venkat Lakshmi (left) and Walter Zimmer check a lidar at the intersection. Bottom: The team (from left): Leah Strand, Andreas Schmitz, Venkat Lakshmi, Walter Zimmer and Christian Creß.

Picture credit: Stefan Woidig

Prof. Alois Christian Knoll

After positions in Stuttgart, Berlin and Bielefeld, Alois Knoll arrived at TUM in 2001 and now leads the Chair of Robotics, Artificial Intelligence and Real-time Systems. Alongside many other activities, he served as Program Principal Investigator at TUMCREATE in Singapore from 2011 to 2021. This time gave him a sense of optimism that modern technology can deliver positive change in the transport system, hoping that even a city like Munich can follow the example of a supercity like Singapore. As part of his work to promote this, he sets great store by close cooperation with business and is deeply committed to young people's training and education.

Looking around corners with digital twins: Cars will know in real time what's happening at the intersection.



"We need to give autonomous vehicles a reliable and immediate answer to the question of what's hiding around the next corner."

Alois Knoll

Graphics: turbosquid, ediundsepp (source: TUM)

“Our high-security data encryption and the safeguards in place to protect system access points means that external users cannot gain access,” emphasizes Knoll.

Fewer severe injuries when turning right

Even though the technical infrastructure of the prototype exists and the digital twin functions effectively, the project is still a few steps away from everyday practice, which requires installing the system across entire cities. Above all, there is still the need to develop easy-to-install, low-cost and modular sensor systems, which will primarily require support from the industry.

Despite this, the overall concept is not some pie-in-the-sky futuristic dream. The newly developed technology in its current modular form can be installed immediately and its full impact realized today. For example, Munich’s police department has reported that more than 90 cyclists were severely injured in 2020 alone because “car and truck drivers failed to see the cyclist when turning right” – and this figure is rising. Alois Knoll considers this irresponsible. “Providentia++ could prevent such accidents by providing a warning in the car before it turns right,” he emphasizes. “An intelligent solution would certainly be better than the small side mirrors we have today. The costs would be manageable for the city, too.”

The future use of the technology developed in the Providentia++ project will not only be wide-ranging but will also lead to it becoming indispensable, as it can support all levels of driver assistance through to autonomous driving. In levels 1 and 2, which describe assisted driving, the system communicates via an interface to provide information in real time that assistance systems can process. In levels 3 to 5, which describe automated driving systems, a constant overview of the current situation is essential, as autonomous vehicles do not have the benefit of a driver’s intuition. Better sensor technology therefore needs to compensate for this. “In effect, we constantly need to give the vehicle a reliable and immediate answer to the question of what’s hiding around the next corner,” says Knoll. He and his staff at the Chair benefit from their extensive expertise in working with robotics. “Classic robotics is, to an extent, the nursery school for autonomous driving.”

■ *Brigitte Röthlein*

Looking into **the Future**

Picture credit: Astrid Eckert/TUM

Link
www.ce.cit.tum.de/air

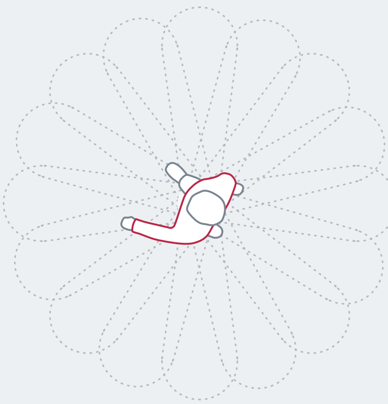
Preventing accidents is the number one priority in the development of autonomous vehicles. With this in mind, Professor Matthias Althoff is working on a procedure to make autonomous vehicles up to 100 % safe. His software can anticipate traffic situations within a fraction of a second – thereby ensuring that the car avoids collisions with other road users.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

Blick in die Zukunft

D

Autonom fahrende Autos dürfen andere nicht gefährden. Um Unfälle und Kollisionen zu vermeiden, müssen sie auf alle möglichen Verkehrssituationen vorbereitet sein. Prof. Matthias Althoff will mit seinen Forschungsarbeiten die Interaktion von autonomen Fahrzeugen mit anderen Verkehrsteilnehmern sicherer machen. Seine Software trifft in Echtzeit eigene Entscheidungen und kann so – Sekunden im Voraus – Gefahren ausschließen. Dazu erfasst das Programm permanent die Verkehrsdaten, analysiert im Millisekundentakt während der Fahrt das Geschehen und prognostiziert den weiteren Verlauf. Die Software berechnet dann für alle Verkehrsteilnehmern die Menge aller Möglichkeiten, ermittelt verschiedene Optionen und kalkuliert gleichzeitig mögliche Notmanöver. Nur wenn eine Route ohne voraussehbare Kollision befahren werden kann und zudem ein Notmanöver möglich ist, darf das autonome Fahrzeug die Strecke befahren. □



Plenty of things can surprise you when driving a car. From a vehicle in front braking sharply to a cyclist suddenly veering into your path or a pedestrian stepping directly onto the road, the range of hazards that can arise in road traffic is just about endless.

In most cases, a person sitting behind the wheel can make an adequate assessment of hazards as they occur and react accordingly. They can anticipate how other road users will behave and preempt their intentions, such as the possibility that a pedestrian standing on the curb might suddenly step into the road.

In their current stage of technological development, autonomous vehicles cannot keep pace with human cognition. For the most part, they rely on patterns they have learned and stored in their memory, driving according to rigid rules – which limits their flexibility in complex traffic situations and increases the risk of accidents. Above all, they need to be prepared to handle as many different scenarios as possible so that they can react appropriately.

Achieving that, however, is anything but simple. Given the gargantuan number of potential combinations of variables, it is simply not possible to determine all possible scenarios in advance. The sharpness and shape of a bend, the width of a lane, the number of other vehicles on the road, directions of travel, different speeds – the possible variants of these central driving parameters generate a vast number of combinations that cannot all be tested.

“Testing alone is not enough to validate an autonomous car,” explains Matthias Althoff, Professor of Cyber-Physical Systems at TUM. “If you wanted to ensure that an autonomous car drives just as reliably as a human with a 95 % degree of certainty, it would have to complete around 440 million kilometers – which would be inefficient.” And, as Althoff points out, a car will never experience the vast majority of scenarios and combinations of potential traffic scenarios.

Real-time decisions

Together with his research team, Matthias Althoff is hoping to help autonomous vehicles react in a similar way to humans. Instead of rigidly following rules they have been taught, the researchers hope to enable autonomous vehicles to make decisions independently in future, thereby eliminating hazards seconds before they occur.

For this to be possible, cars will need the ability to think ahead when driving and anticipate traffic situations, just as people do. “To achieve this goal, we look at everything that other road users could do,” says Althoff. Before a self-driving vehicle sets off, Althoff’s software system calculates the multitude of possible situations that could occur fractions of a second later. This “set of reachable states” is the heart of the entire concept.

The procedure behind it is called reachability analysis. It involves calculating, for example, which positions a car or a pedestrian could feasibly occupy in the next few seconds. “Determining these sets of states and reconciling everything with motion planning for other vehicles is not easy," explains Althoff. Moreover, because determining a set of states requires sophisticated calculations, Althoff makes do with simple models that are easier to capture mathematically.

At the same time, the set of states is used to design an emergency maneuver. This could be to brake sharply or speed up so that the vehicle can be guided to a safe place without endangering other people. "We always have an emergency maneuver to hand that can take us to a safe state," says Althoff. "The vehicle can only drive a given route if no collisions are foreseeable and an emergency maneuver can be performed."

"Testing alone is not enough to validate an autonomous car."

Matthias Althoff

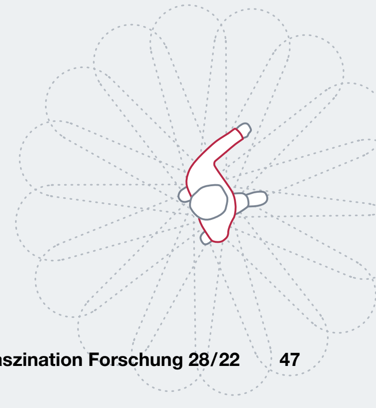
Better reactions

Together with his team, Althoff has translated this theoretical concept into a software module that constantly analyzes and predicts incidents while a vehicle is driving. In the first step, the program uses camera and radar data to capture all nearby road users at millisecond intervals.

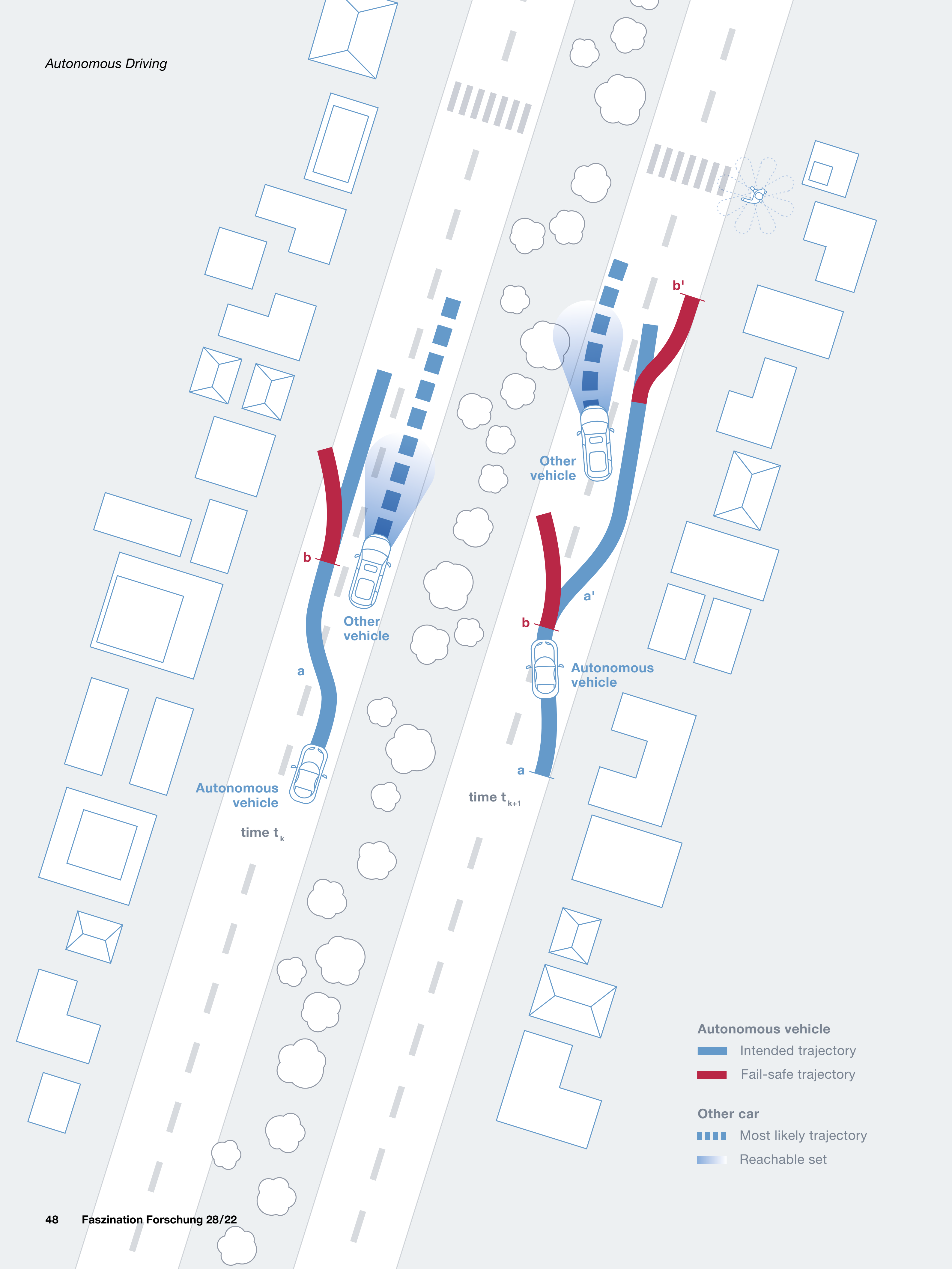
Based on this data, it calculates the set of reachable states – that is, the potential movements of the other road users in the next few seconds. This analysis allows the software system to look three to six seconds into the future. Using these calculations, the program then defines several motion options for the car's maneuver – including the emergency maneuver. However, there is one limitation to this. The vehicle's actions must also comply with road traffic regulations at all times.

This new approach could usher in a paradigm shift for autonomous vehicles. Althoff's software enables cars to react more effectively to unexpected road traffic incidents not foreseen by manufacturers. Not only has the Munich-based research team shown that real-time data analysis and simultaneous simulation of future traffic situations is theoretically possible, they have also delivered the mathematical proof that it achieves reliable results. Real-world road testing is currently underway.

■ *Klaus Manhart*



Graphics: ediundsepp


Other vehicle
b
a
Autonomous vehicle
time t_k
Other vehicle
b'
a'
b
Autonomous vehicle
a
time t_{k+1}
Autonomous vehicle
Intended trajectory
Fail-safe trajectory
Other car
Most likely trajectory
Reachable set

Prof. Matthias Althoff

received a diploma in Mechanical Engineering in 2005 and his PhD in Electrical Engineering in 2010, both from TUM. From 2010 to 2012, he was a postdoctoral researcher at Carnegie Mellon University in Pittsburgh, USA, followed by a stint as Assistant Professor at the Technische Universität Ilmenau from 2012 to 2013. Since then he has been a professor in computer science at TUM. His research interests include the formal verification of continuous and hybrid systems, reachability analysis, planning algorithms, non-linear control, automated vehicles, and power systems.

◁ **Planning for the unexpected**

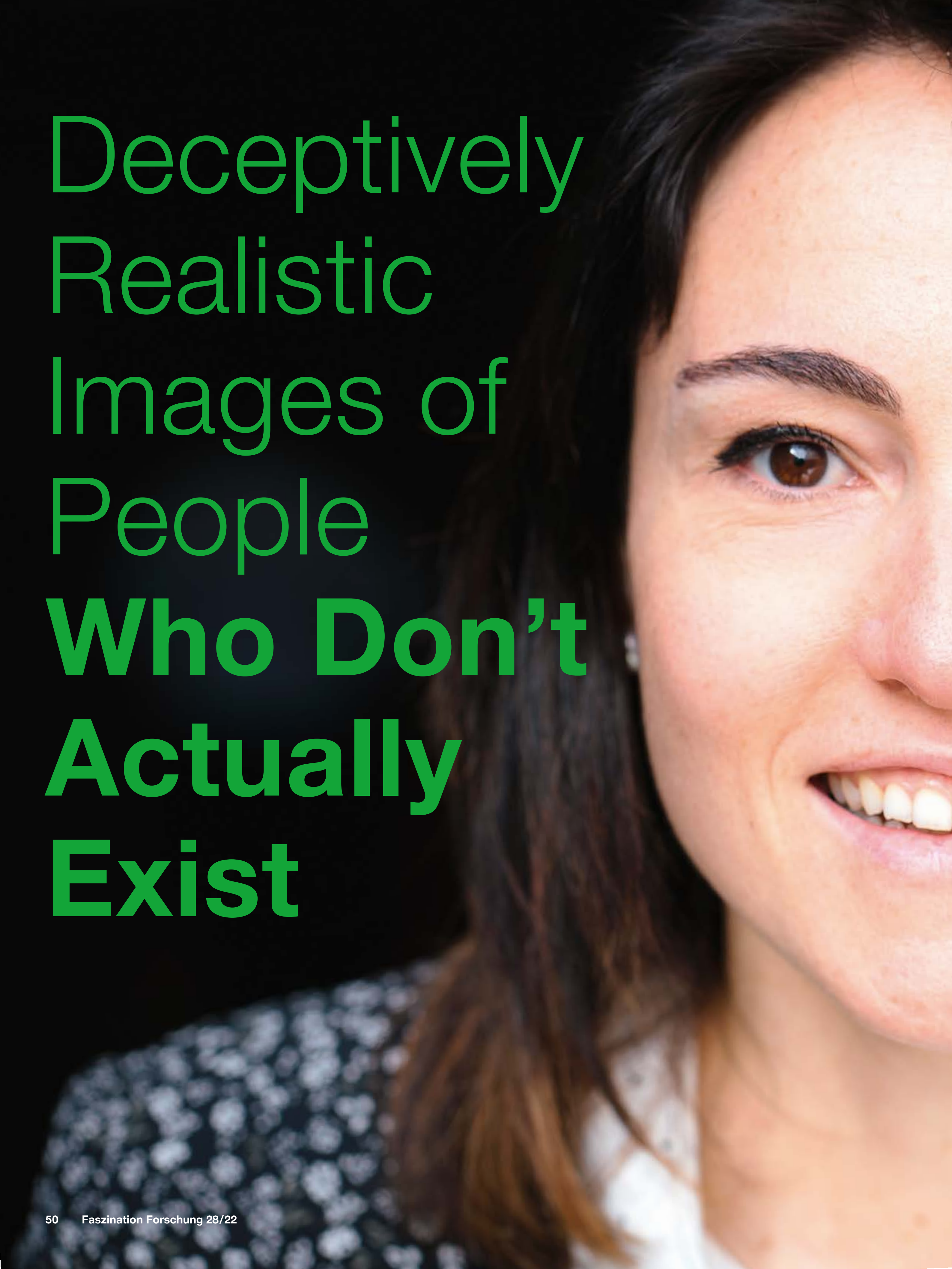
The graphic illustrates the software module developed by Matthias Althoff to achieve safe autonomous driving. In the initial scenario, the autonomous blue car wants to overtake another slow car in front of it. Just like a human driver, the autonomous vehicle assumes that the other car will stay in the same lane and continue to drive at the same speed.

Althoff's concept involves analyzing the behavioral scope of the car to be overtaken – that is, its range of potential behaviors. This is known as the set of reachable states. In the example, a and a' are two sections of the planned movement. At the same time, the system designs an emergency maneuver (b and b'). This maneuver becomes important if no future safe behavior can be found. In this case, the autonomous car must execute the emergency maneuver to return to a safe state.

Only when a and b have been verified does the autonomous car start the maneuver, at time step t_k in the diagram. At time step t_{k+1} the other car makes an unexpected and sudden lane change. The original emergency maneuver, b, remains safe – but the autonomous vehicle does not need to brake unnecessarily and come to a halt.

This is because a new solution, a', has arisen dynamically along with a corresponding emergency maneuver, b' – both of which must be safe, taking the behavior of the other vehicle into account. Once this solution has been verified, the autonomous vehicle can follow this new route.

Picture credit: Astrid Eckert/TUM; Graphics: ediundsepp (source: TUM)



Deceptively Realistic Images of People **Who Don't Actually Exist**

Neural nets in self-driving cars require vast quantities of images of road traffic to learn how to recognize people. However, using these recordings requires the consent of the people recorded in them – which would be an enormous undertaking. A research group led by Prof. Laura Leal-Taixé has found intriguing solutions to this problem.

Link
dvl.in.tum.de/team/lealtaixe

Picture credit: Magdalena Jooss, L. Leal-Taixé

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

Täuschend echte Bilder von Personen, die es nicht gibt

D

Es betrifft alle Einsatzbereiche von Künstlicher Intelligenz: Neuronale Netze, seit einigen Jahren die unersetzlichen Arbeitstiere der KI, erlernen ihre Aufgaben durch Training mit ungeheuren Mengen von Daten. Oft sind es Bilder von Personen, etwa wenn ein autonomes Fahrzeug lernen soll, Menschen zu erkennen und ihnen auszuweichen. Doch solche Daten sind sensibel, die abgebildeten Menschen müssten um Erlaubnis gefragt werden. Prof. Laura Leal-Taixé erforscht mit ihrem Team Verfahren, die in der Lage sind, datenschutztechnisch unbedenkliche Bilder von Menschen zu generieren. Sie verfolgt dabei unterschiedliche Zugänge: Einerseits werden in Abbildungen von Menschen die realen Personen durch computergenerierte Personen ersetzt, die in der Realität nicht existieren. Andererseits können auch Bilder verwendet werden, die zur Gänze am Computer entstanden sind. Zum Generieren verblüffend realitätsnaher Bilder von Fußgängergruppen nutzt die Forscherin das populäre Videospiel Grand Theft Auto V. □

Prof. Laura Leal-Taixé

leads the Dynamic Vision and Learning working group at TUM. The Barcelona-born computer scientist completed her Master's thesis in Boston and gained her doctorate at Leibniz University Hannover before taking up research positions in Michigan and Zurich. She transferred to TUM in 2016, winning the Sofja Kovalevskaja Award one year later and the Google Faculty Award in 2020. Leal-Taixé exercises to unwind and has discovered bouldering since arriving in Munich.

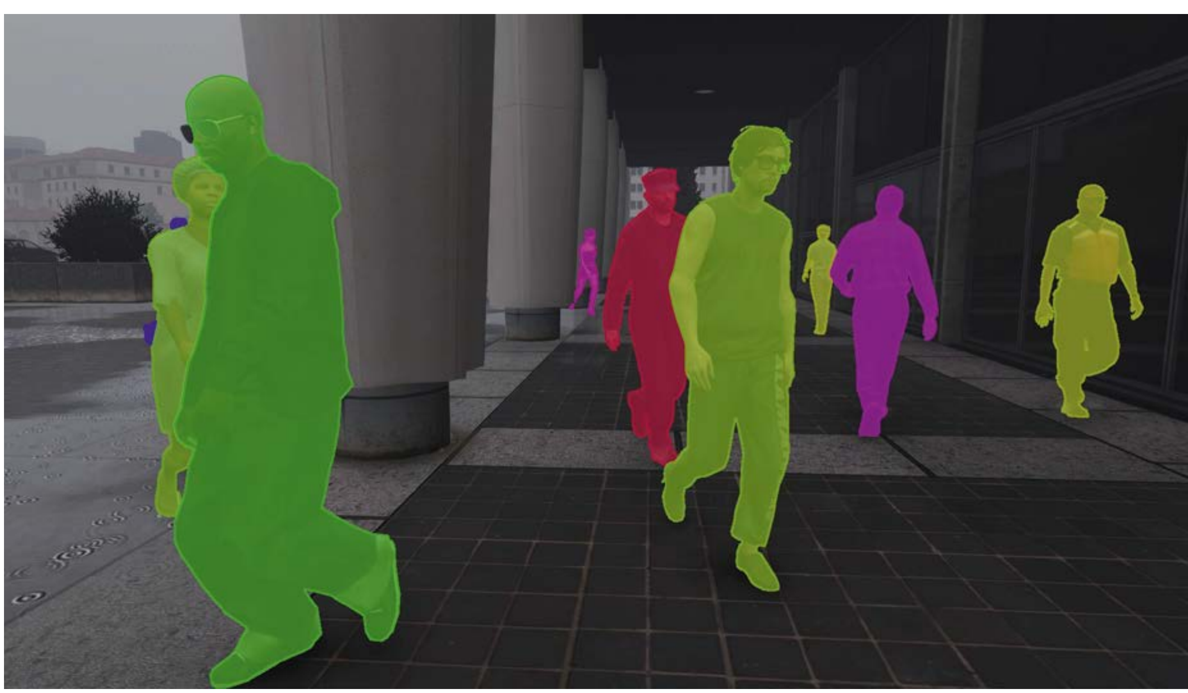
Picture a street, somewhere in Los Angeles. Groups of pedestrians are standing at a traffic light, waiting for the signal to cross. When the light changes, they all set off, weaving and sidestepping each other as they walk to the other side. At first glance, these appear to be entirely normal people living normal lives in a big city, wearing different clothes, of different ages, different genders and different ethnicities. They don't seem to notice that they're being observed.

The person monitoring their activities on the screen is computer scientist Laura Leal-Taixé. Together with her team, she is putting together an extensive dataset that will enable intelligent computer programs to learn to recognize and track people in video images – a key ability for self-driving cars. This requires immense volumes of detailed images of realistic urban environments – and the images that flicker on Leal-Taixé's screen are also of high quality. Even the faces are clearly recognizable. But what about the personal rights of the people in these images? None of them have given their consent to be recorded. Given that training neural nets requires large groups of people, obtaining declarations of consent from all of them would be a mammoth logistical undertaking. And what would the researchers do if just a single person refused? Yet, Leal-Taixé has not let such quibbles affect her work as, upon closer examination, all is not as it first appears. The images on her monitor are not real; instead, they come from one of the world's most popular video games. Her team employed methods from the gaming scene to make the game useful for scientific purposes. And, in doing so, they found a surprising solution to one of the trickiest problems in computer science.

Conflict between data protection and technology

Image recognition is Laura Leal-Taixé's specialist field – and specifically the recognition of people in camera images. This technology is highly sensitive. "These methods could be used for nefarious purposes," she emphasizes. "However, sectors such as the automotive industry urgently need these capabilities." The researcher is not willing to simply leave this conflict unresolved. "It must be possible to find a balance between the two aspects. We want to solve this problem," says Leal-Taixé. ▹

Picture credit: Magdalena Jooss



△ **Images of people in video games** are suitable datasets for training neural nets. The research team has produced a massive set of training data from such images.

▷ **Video game images** already provide the information needed to track pedestrians and infer their pose.

Exactly how to reconcile the process of generating enormous quantities of data with the personal rights of data subjects is a key issue in the field of artificial intelligence. There is no shortage of voices issuing warnings, predicting that Europe will fall behind technologically if regulations are not relaxed for research projects. Many argue that research interests should be given priority over personal rights.

This is exactly where Leal-Taixé and her research group have focused their work, highlighting different ways to generate the requisite training data for algorithms without infringing on individuals' privacy.

Deceptively realistic video games

One solution is to create entirely computer-generated training images. Rather than programming these images from scratch, the researchers can draw on a pop culture phenomenon. The video game industry has been growing rapidly for many years, so much so that its sales figures have now eclipsed those of the global film industry. Realism is a crucial selling point and, as computer hardware becomes more powerful, is also becoming increasingly achievable. Past research projects have already demonstrated that images of people in video games are suitable for training neural nets. Leal-Taixé's team has now produced a massive set of training data from video game images.

Her work has focused on the popular game Grand Theft Auto V, often known simply as GTA V. Set in a major city modeled on Los Angeles, the game features impressive realism and allows players to move around freely. Beyond its realism, however, GTA V presents another vital advantage: it has become a firm favorite of "modders" – people who create modifications for video games as a hobby. Ready-made software tools enable modders to intervene in games, including by placing people at specific locations.

Useful background information

Not only does this approach avoid issues concerning personal rights, it also offers several further advantages. In real images, for example, it is important to identify the information that is actually in images, such as the real coordinates of the people in the images, in order to compare them with the results of the algorithms being trained.

▷

Picture credit: Fabbri et al. 2021: MOTSynth: How Can Synthetic Data Help Pedestrian Detection and Tracking? arxiv.org/abs/2108.09518 (retrieved 13.6.2022).

Left: Segmentation masks
Right: Bounding boxes and keypoints of the person's skeleton describe the pose

This is known as determining the "ground truth" and can be very time-consuming. In computer games, however, the underlying information is always available and can be accessed directly.

But is synthetic image data generated by an entertainment system genuinely realistic enough to train algorithms for use in road traffic? Leal-Taixé warns against unreasonable expectations: "If you only use synthetic data in your training, the performance with real image data will not be perfect. Neural nets are very sensitive when it comes to image texture." One way to remedy this shortcoming is to follow video-game image training with training using real-life images that have been anonymized to protect the personal rights of the people in them.

Blurring is not enough

Anonymizing real photos is another research focus of Leal-Taixé's team. The most common way to anonymize personal data is to blur or pixelate faces. However, Leal-Taixé notes several issues with this approach. "If you only anonymize a person's face, they might still be identifiable by other physical characteristics. We also can't train an algorithm to identify people using images where faces are missing. The images need to be as realistic as possible," she says.

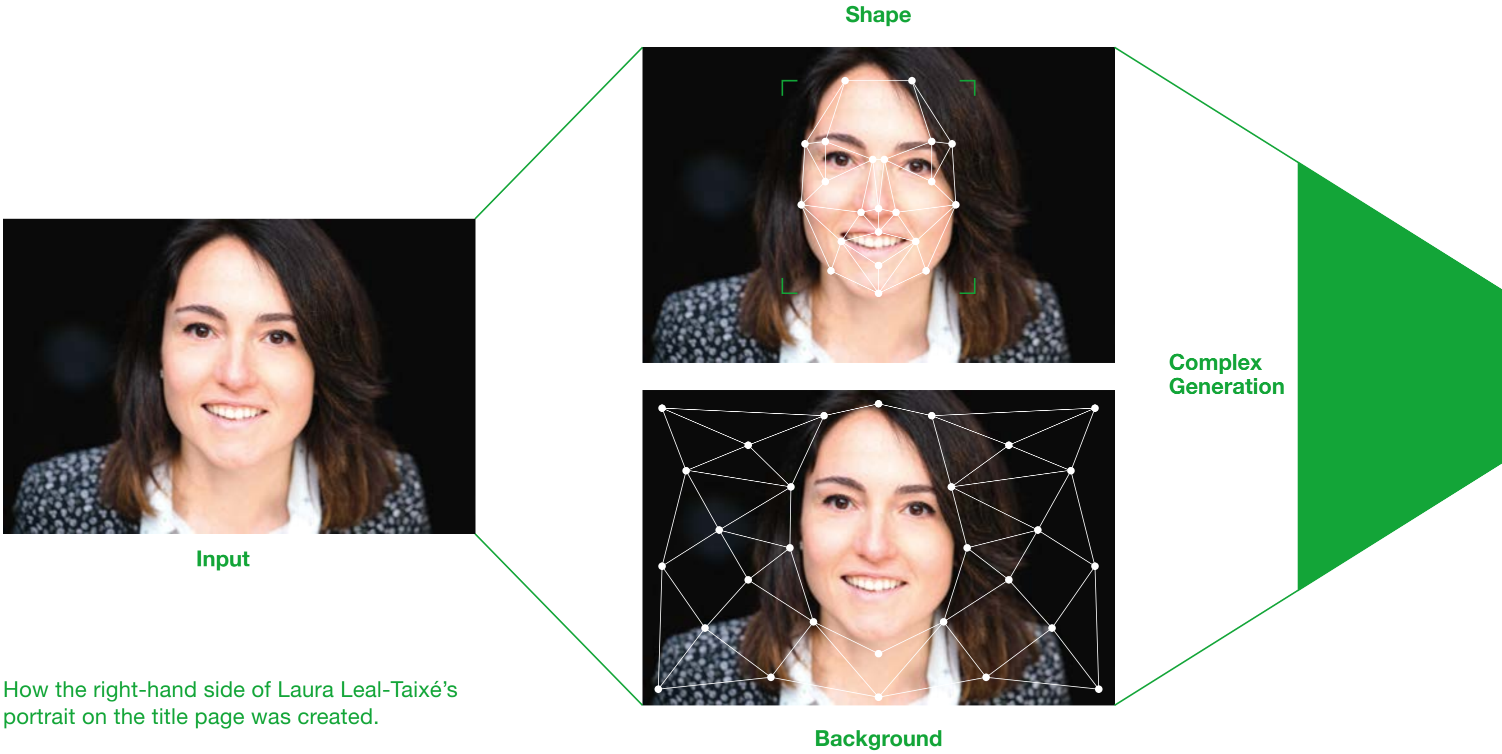
This is why, for some time, there have been attempts to distort images of people so that they can no longer be recognized by their faces. Yet even this is not always effective: it has been demonstrated that, in many cases, distorted faces can be reconstructed in full. "Deepfakes", which have gained attention as something of an Internet phenomenon and involve replacing a person's face with somebody else's with remarkable precision, still do not solve the problem – as the owner of the new face also has personal rights. So, the Munich-based research group has been forced to go one step further. They have shown that it is possible to remove people from images and replace them with entirely computer-generated individuals who look real but do not exist in reality. ▷

Anonymization methods in comparison. From top: original; CIAGAN process developed by Leal-Taixe's team; blur (17 x 17 and 9 x 9); pixelation (16 x 16 and 8 x 8); image-to-image translation (Pix2Pix and CycleGAN)

“If you only anonymize a person’s face, they might still be identifiable by other physical characteristics. We also can’t train an algorithm to identify people using images where faces are missing. The images need to be as realistic as possible.”

Laura Leal-Taixé

Picture credit: Maximov et al. 2020: CIAGAN: Conditional Identity Anonymization Generative Adversarial Networks. arxiv.org/abs/2005.09544,
Liu et al. 2015: Deep Learning Face Attributes in the Wild. mmlab.ie.cuhk.edu.hk/projects/CelebA.html (retrieved 13.6.2022).



How the right-hand side of Laura Leal-Taixé's portrait on the title page was created.

Privacy-preserving

fake images ...

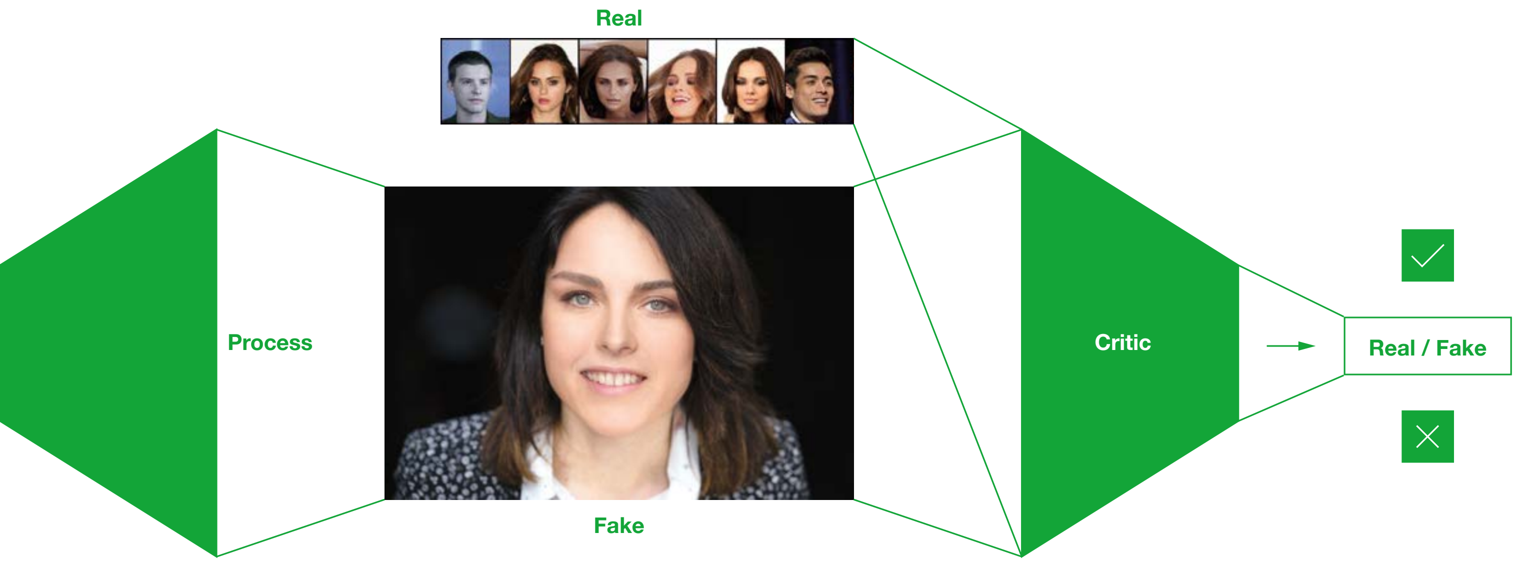
Also suitable for video footage

But is that enough to support smart mobility applications? Ultimately, moving images are subject to special requirements. If the researchers replaced a person frame by frame, it could result in jerky, unrealistic movements. "We need image stability across multiple frames in a video so that we can train algorithms to track people," says Leal-Taixé. This is possible by first focusing on determining so-called "landmarks". "In terms of faces, these include the tip of the nose, the eyes and the mouth," the researcher explains. A person's posture is another such landmark. Identifying landmarks makes it possible to recognize and imitate and person's pose, thereby preserving a realistic movement pattern in moving images.

While one neural net generates the fictitious people, a second neural net monitors the success of the process by trying to identify the people. If it cannot identify them, it serves as proof of successful anonymization.

Although this research is still at an early stage, this appears to be a highly promising approach. Leal-Taixé's group has successfully generated realistic images of people who do not really exist.

Picture credit: Magdalena Jooss, L. Leal-Taixé, Maximov et al. 2020: CIAGAN: Conditional Identity Anonymization Generative Adversarial Networks. arxiv.org/abs/2005.09544 (retrieved 13.6.2022). Graphics: ediundsepp (source: TUM)



Anonymizing faces in a way that they are not identifiable but detectable for tracking: The input image together with its landmark (eyes, nose, mouth) and shape are fed into a complex image generator to produce a fake image. This image is then scrutinized in a separate process to ensure that real persons cannot be identified.

Young working group

Leal-Taixé relies on a young team in this project. Shortly after transferring to TUM, one of her projects was recognized with the Alexander von Humboldt Foundation's Sofja Kovalevskaja Award. The € 1.65 million endowment enabled her to establish a working group. She believes that the student pool and open environment have offered the ideal conditions for her work. "The students are exceptionally well prepared and we would love to be able to supervise more theses."

As it happens, when Leal-Taixé shuts down her computer and heads home for the day, she leaves the video games in the office. Her interest is purely professional, though that wasn't always the case. She also enjoys playing open-world games like GTA in her leisure time – a secret vice, she admits. Since the birth of her daughter, however, she has little time for that. Instead, she prefers to let algorithms play the games, so they can learn to evade real people on the roads in the future.

Reinhard Kleindl

... allow for detection but

prevent identification

Link

www.mos.ed.tum.de/vt
tempus-muenchen.de

Automated Driving Will Require a **New Traffic Culture**

Automated driving is a vision of the future with more than just technical implications. In creating a safer, efficient, sustainable yet convenient traffic system, the complex interaction between people and vehicles has a central role to play. TUM is engaged in the TEMPUS research project, which hopes to highlight ways that technology and a new traffic culture might influence and shape this relationship.

Graphics: turbosquid, ediundsepp

Road traffic today:
Fixed lanes

Lane-free
traffic

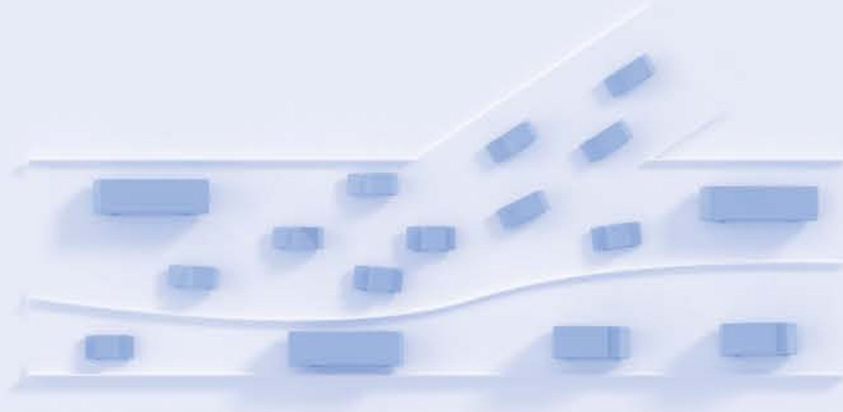
Automated vehicles using cameras and sensors to keep an eye on each other while also exchanging data do not need fixed lanes but can organize themselves depending on the actual traffic situation.

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

Automatisiertes Fahren braucht eine neue Verkehrskultur

D

Immer stärker automatisierte Fahrzeuge legen die Grundlage für einen sicheren, nachhaltigen und zugleich komfortablen Verkehr in der Zukunft. Viele Prototypen mit ausgeklügelten Regelungen, Sensoren und Kamerasystemen sind technisch bereits weit gereift. Doch auch das komplexe Wechselspiel zwischen Mensch und Fahrzeug muss für einen Erfolg eines automatisierten Verkehrs dringend beachtet werden. Dazu forscht Prof. Klaus Bogenberger mit seinem Lehrstuhl am Projekt TEMPUS. Es soll wichtige, bisher kaum verfügbare Daten aus dem Verkehrsalltag im Norden Münchens liefern, um Technologie und das Verhalten der Menschen in Einklang zu bringen. Dabei spielen optimierte Reaktionen automatisierter Fahrzeuge auf besonders verletzliche Verkehrsteilnehmer wie Fußgängerinnen und Radfahrer eine zentrale Rolle. Zusätzlich werden mit Prototypen und Simulationen neue Konzepte sowohl für den öffentlichen Nahverkehr und Lieferdienste als auch für einen effizienteren Verkehrsfluss ohne jegliche Fahrspuren erprobt. Am Ziel dieser Entwicklung kann eine völlig neuartige Verkehrskultur stehen. □



Vehicles use the road width in an optimal way

Automated vehicles organize themselves in flocks to optimize intersection capacity

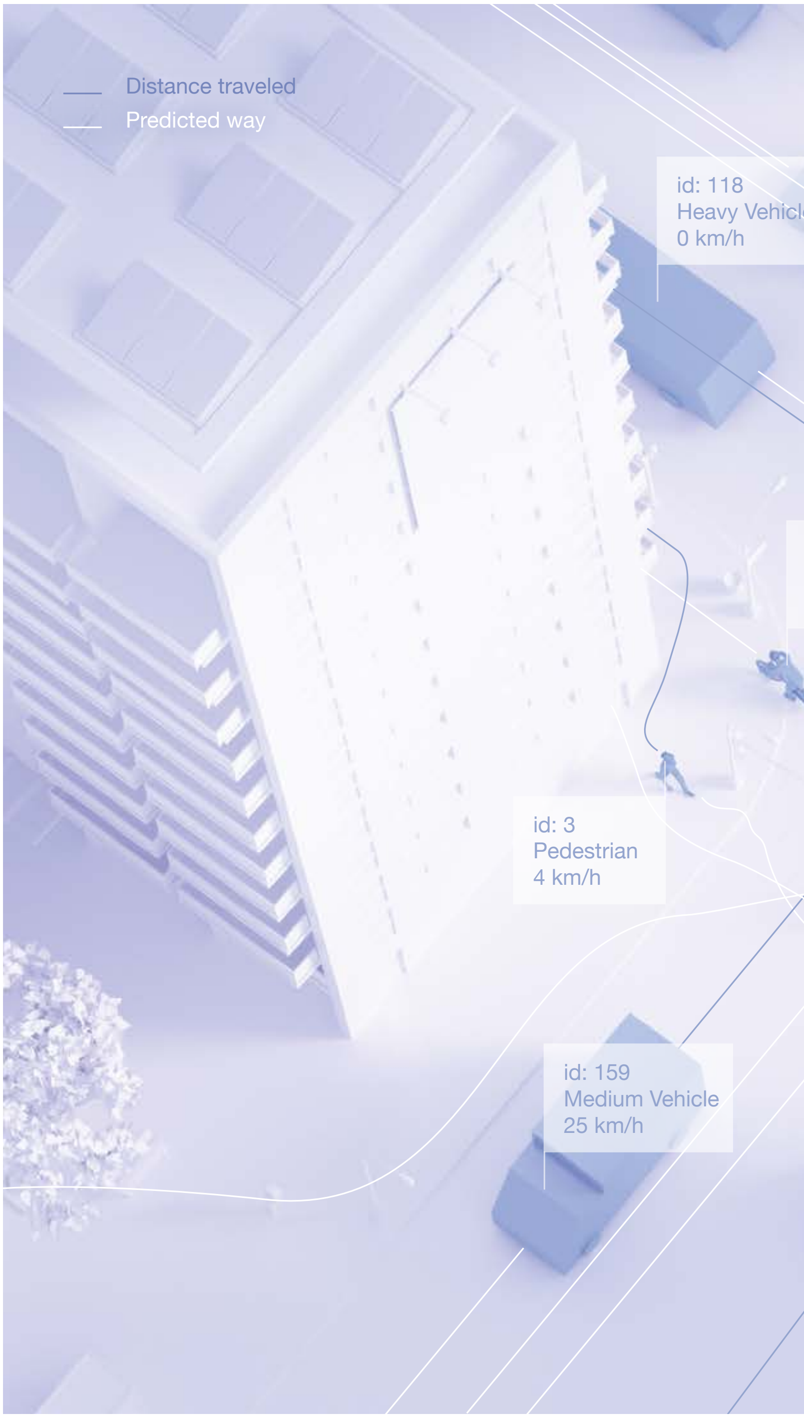
Automated vehicles could enable the same roads to accommodate one-third more traffic than today.

Anarchy is not uncommon on the roads of Buenos Aires. Many drivers ignore red lights, especially at night. On Avenida del Libertador, one of the city's principal thoroughfares, the drivers treat the 16 clearly marked lanes as a suggestion at best. Nevertheless, vehicles weave their way past each other with uncanny caution along this expansive road. Blaring horns and even accidents are rare events. This traffic culture is certainly no blueprint for a major German city – and yet, a seemingly frenzied tangle across all lanes is a conceivable possibility in Germany in the near future. High numbers of automated vehicles using cameras and sensors to keep an eye on each other while also exchanging data could make this possible. This would take human drivers' attentiveness out of the equation entirely in order to achieve a high degree of safety for all road users. "It would enable the same roads to accommodate one-third more traffic than at present," says Klaus Bogenberger, Professor for Traffic Engineering and Control at TUM.

More fluid traffic on lane-free roads is just one of many forward-looking concepts that the traffic researcher is currently examining in the TEMPUS project along with around a dozen partners from the fields of administration, research, business and industry. The project is funded by the German Federal Ministry for Digital and Transport, its full name is TEMPUS – Testbed Munich – Pilot Test of Urban Automated Road Traffic. TUM project leader is Martin Margreiter, Head of the Chair's Research Group Automated Traffic. Lane-free traffic is among the topics the researchers are currently examining exclusively using computer simulations. However, the TEMPUS project's focus as it seeks to secure a safer, sustainable and convenient future for traffic lies in practical application. How will automated vehicles find their way in traffic? How will they react to pedestrians or cyclists – and vice versa? What rules will be needed to help traffic flow and, above all, to flow safely? And how can we program automated vehicles' control systems to meet these demands? The TEMPUS project, which has been awarded €13 million of funding from the Federal Ministry for Digital and Transport over a 30-month period, aims to find pioneering answers. ▷

Graphics: turbosquid, ediundsepp (source: TUM)

“Some automated vehicles will be driving on a TEMPUS testing area as early as this summer,” says Bogenberger. Situated in the north of Munich, this testing area stretches from Olympiapark via Unterschleissheim and all the way to the A9 and A99 autobahns. The automated vehicles – including cars from BMW and buses made by the Dutch firm Ebusco – will have to integrate into real traffic, both in urban residential areas and on federal roads and autobahns in rural areas. “This test field includes all road types, making it the first of its kind anywhere around the world,” says Bogenberger. The automated vehicles will constantly receive real-time traffic data via high-speed 4G and 5G networks. In addition, crossings will be equipped with intelligent traffic lights, while detection loops in the roads will be used to monitor the vehicles along with cameras and drones. “Another goal for TEMPUS is to standardize data flows,” says Bogenberger. As he explains, this is the only way the system will be able to function at every traffic light in Europe in the future.



It is hoped that automated vehicles’ intelligent real-time control systems will make it possible to avoid sudden traffic jams and congestion while also benefiting local public transport services. In fact, the TEMPUS partners are testing a system in which an automated bus independently follows a classic bus with a human driver at times of high passenger numbers – like a duckling following its mother. This solution, known as bus platooning, improves the service for public transport passengers while also saving energy and road space. Another sub-project is considering the potential of ride-parcel-pooling as a way to cope with the significant increase in parcel shipments due to the rise of online retail. In this scenario, ride-sharing services – such as the MOIA, a mobility service somewhere between a taxi and local public transport, operated by the Volkswagen Group – pick up and transport both passengers and parcels. This would reduce the number of automated vehicles on the road by making better use of their capacity, thereby reducing traffic levels and congestion.

Interaction with pedestrians and cyclists

“In contrast to many previous pilot projects with automated vehicles, in the TEMPUS project we’re focusing in particular on the interaction with pedestrians and cyclists,” says Bogenberger. The researchers use cameras and small drones to film real-life traffic over several hours, such as at junctions. They hope this will help them to understand how people react to automated vehicles in different scenarios. The central aim is to develop a vehicle control system capable of avoiding accidents if at all possible and thus prevent injuries to pedestrians and cyclists. One conceivable solution would be programming that gives cyclists priority in high-risk situations rather than doubling down and driving on. It might also instruct cars to brake for pedestrians crossing the road with an arm

Graphics: turbosquid, ediundsepp (source: TUM)

outstretched. Another possibility would be to install light signals on automated vehicles to let pedestrians know they had been seen. Bogenberger expects the project to deliver vital insights for which automated vehicle manufacturers will be extremely grateful. “It’s getting very exciting because there’s only very little data about this worldwide,” explains Bogenberger. ▷

Within the TEMPUS project, drones will observe real-life traffic such as at junctions in order to understand how cyclists and pedestrians interact with automated vehicles.

▽ Left: The researchers develop a traffic model for the city of Munich. Right: Specially constructed rickshaws are used for pilot trials on ride-parcel-pooling and automated traffic.

△ A field trial with a rickshaw investigates the potential of ride-parcel pooling to improve environmental and transportation parameters.

Picture credit: Stefan Woidig

Prof. Klaus Bogenberger

After studying civil engineering at TUM, Klaus Bogenberger focused his attention on traffic planning. He received his doctorate in this field in 2001 and was awarded the Heureka Award for Young Scientists. Bogenberger gained industrial experience in roles at the BMW Group and, from 2008, as a managing partner in Munich-based firm Transver. He was appointed a full professor in Traffic Research at the Institute of Spatial Planning and Transportation at the Universität der Bundeswehr München and has held the Chair of Traffic Engineering and Control at TUM since 2020. His working group concentrates on complex simulations of traffic flow theories in cities and on motorways. Further research focuses include sharing systems and new forms of local public transport, such as on-demand services, robot-taxi systems and urban ropeways.

However, the traffic engineer is especially proud of one aspect of the TEMPUS project in particular: "By working with local authorities, industry and research, we have been able to bring all key stakeholders together. That's not an easy task in the transport sector." In addition, TEMPUS has made citizen participation a top priority, inviting them to contribute their experiences with automated vehicles via various channels and at local events. Bogenberger believes that local authorities, as citizens' representatives, have an important responsibility to lay the cornerstones of a new traffic culture. "They have jurisdiction over transport matters and now have the opportunity to draw up rules. They don't need to wait for guidelines from technology firms," he says. In many cases, Bogenberger explains, local authorities are not even aware of the influential power they hold.

So, how does Bogenberger assess the likelihood of vehicles scurrying along paying no attention to lanes? "It could become a reality, most likely on motorways. However, it would require an awful lot of automated vehicles in traffic." That time could come, he suggests, in the next few years. "After all, the dynamic electromobility landscape we have today got off to a very slow start a few years ago," he says, as he looks to an automated future for traffic.

■ *Jan Oliver Löfken*

All Daily Needs Within **15 Minutes**

In sustainable cities, cars have only a minor role to play. Instead, people travel from A to B on foot or by bicycle. A start-up called Plan4Better hopes to promote this transition with its planning software, which a number of municipalities have already adopted.

When it comes to deciding where to build a new footpath or cycle lane, many officials rely on gut feeling alone. Specialist planning software does exist, but only for road traffic. As a result, many project proposals end up gathering dust in desk drawers and never actually come to fruition.

Plan4Better hopes to change precisely that. Founded in January 2021, the start-up is the brainchild of Elias Pajares, Ulrike Jehle and Majk Shkurti. While studying for his Master's degree at TUM's Chair of Urban Structure and Transport Planning in 2017, Pajares started to develop a software solution called the Geo Open Accessibility Tool, or GOAT. This makes it possible to model reachable destinations for pedestrians and cyclists.

Majk Shkurti joined as a freelance software developer in 2018. Ulrike Jehle came on board in 2019 while completing her Master's thesis. With the team complete, the trio knew they were working on something that deserved more than to gather dust in a desk drawer. The result is a tool for planners in municipalities, counties and planning offices.

Planning reachable destinations

When a user opens the program, the first thing they see is a map of their city. They can then choose any starting point and view how far they could travel within 5, 10 or 15 minutes by foot or by bicycle. The map also includes public amenities and sites of public interest, such as bakeries, mailboxes and clothes stores.

Users can enter new footpaths and cycleways in just a couple of clicks. The software then immediately calculates the resulting accessibility improvements. Another functionality is the ability to enter a new kindergarten, for example, and view how many people live within a 15-minute radius. The trio have been supported in developing the tool by Professor Gebhard Wulfhorst, Dr. Benjamin Büttner and the entire team at the Chair of Urban Structure and Transport Planning. Plus, in an effort to ensure the software is genuinely practical, Plan4Better has collaborated closely with the municipal authorities in Fürstenfeldbruck and Freising and the City of Munich from the very outset. "Workshops with practitioners enabled us to identify what works well and where we needed to make improvements," says Jehle.

However, creating a good product is only half the battle; entrepreneurial expertise is also essential. TUM Start-up Consulting assisted in this respect. In addition, Plan4Better was accepted into the TUM Venture Lab Built Environment and invited to take part in the XPRENEURS program at UnternehmerTUM – which included numerous training events on topics such as sales strategies and marketing.

Start-up and innovation awards

In recent years, Plan4Better has won numerous awards, including the Smart Country Startup Award in the "Smart City" category from German digital association Bitkom, the Munich Innovation Prize in the "Emission-free Mobility in Munich" category from the City of Munich, and the Startup Award from the Federal Ministry of Economic Affairs and Energy (BMWi). In November 2021, the start-up launched a three-year research project, GOAT 3.0. With over €500,000 in funding, the majority provided by the Federal Ministry for Digital and Transport, the project aims to expand GOAT with functionalities including accessibility analyses for on-demand services and journeys using a combination of transport types, such as cycling and public transport.

Meanwhile, however, Plan4Better has already secured its first paying customer: the City of Freiburg. Negotiations are currently ongoing with other cities in Germany, Switzerland and the USA. The City of Munich has also used GOAT in handling a handful of planning issues. "It would obviously be a dream if Munich, our base, were to adopt our software for the long term and make it available to all its planners," says Jehle.

Claudia Doyle

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

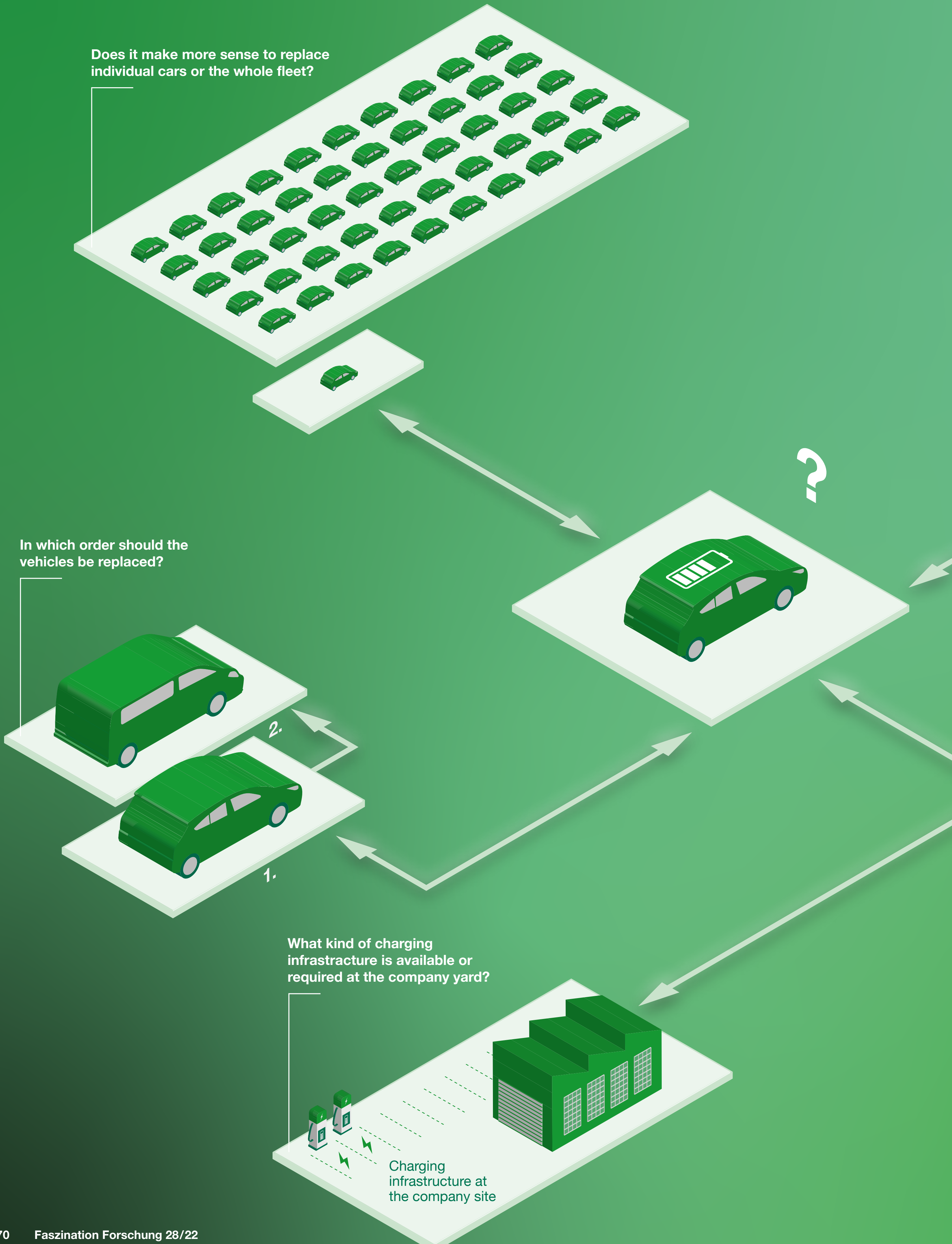
In nur 15 Minuten an jeden Ort

D

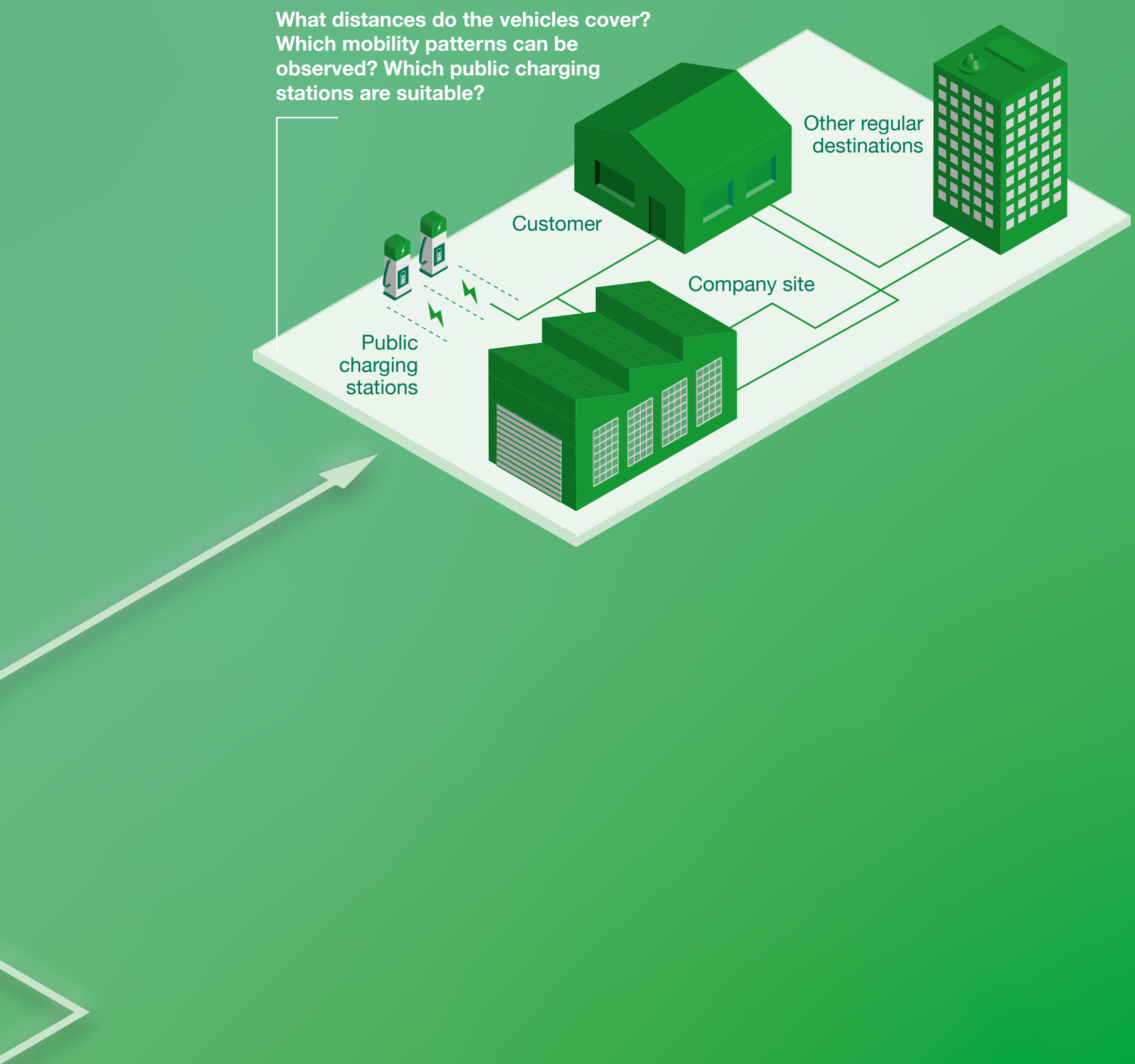
Nachhaltige Städte brauchen kurze Wege. Plan4Better will dazu beitragen, dass jeder von seiner Wohnung aus in nur 15 Minuten zu Fuß oder mit dem Fahrrad alle Orte von öffentlichem Interesse erreichen kann.

Link
www.plan4better.de

Graphics: ediundsepp, © Mapbox, © OpenStreetMap



Does it make more sense to replace individual cars or the whole fleet?
?
In which order should the vehicles be replaced?
2.
1.
What kind of charging infrastructure is available or required at the company yard?
Charging infrastructure at the company site



How Much Electromobility Do You Need?

Link
www.mos.ed.tum.de/ftm

Graphics: ediundsepp

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

Wie viel E-Mobilität darf's denn sein?

D

Ist Elektromobilität für mich bzw. für mein Unternehmen sinnvoll und lukrativ? Welche Elektromobilitätslösung bietet sich an? Antworten liefert WATE. Das digitale Beratungstool analysiert anhand des Mobilitätsverhaltens, ob bzw. welche Elektroautos geeignet wären – und steht für Forschungsprojekte parat. □

Would e-mobility be a sensible, lucrative choice for me and my company? Which solutions would be most suitable? WATE has the answers.

Here's a scenario: A Munich-based trade business has nine vehicles, from utility vans to speedy urban runabouts. The managing director is now considering electrifying the fleet – to save costs, reduce emissions and thereby do something good for the environment. It's a decision that needs to be carefully weighed up. WATE, the Web-based Analysis Tool for Electromobility developed at TUM, can provide valuable assistance.

In the first step, WATE records motion data for each of the vehicles. This involves either an app or a data logger. In this case, the manager opts for the data logger, which has also been developed in-house at TUM and records data with even greater accuracy than the app. From the very first day, she can view virtual logbooks and access interactive analyses: How many kilometers are my vehicles driving? Where exactly are they? How long are their journeys, how fast are they driving, and how long are they stationary? After WATE spent a few weeks collecting data, it is time for the all-important question: Would it make sense to switch my vehicles from conventional combustion engines to battery electric vehicles (BEV)? WATE can test out that scenario by conducting simulations. This entails referring to a vast database containing the key energy consumption characteristics of BEV. The manager can now play out different scenarios. What would happen if she replaced the city cars or utility vans with battery electric alternatives? What models are available? Weather is also taken into account, for example; after all, the battery loses energy more quickly in cold temperatures and therefore has a shorter range in winter. WATE, however, not only analyzes the vehicles themselves but also the charging infrastructure. Would private

“WATE is a brilliant tool for playing out what-would-happen-if scenarios.”

Lennart Adenaw

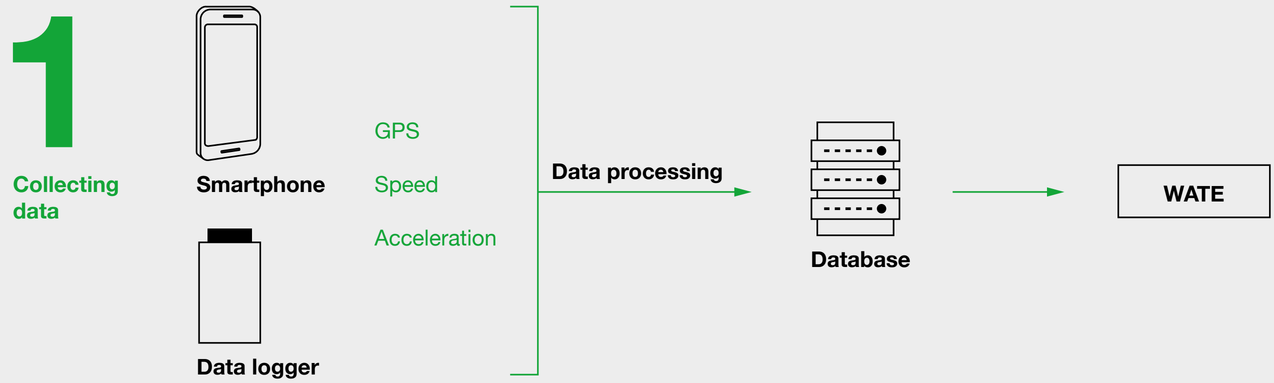
or public charging points be able to provide the EVs with a sufficient supply of electricity? Beyond that, WATE can also forecast suitable charging point configurations in terms of their number and output as well as the potential synergies with an in-house photovoltaic system.

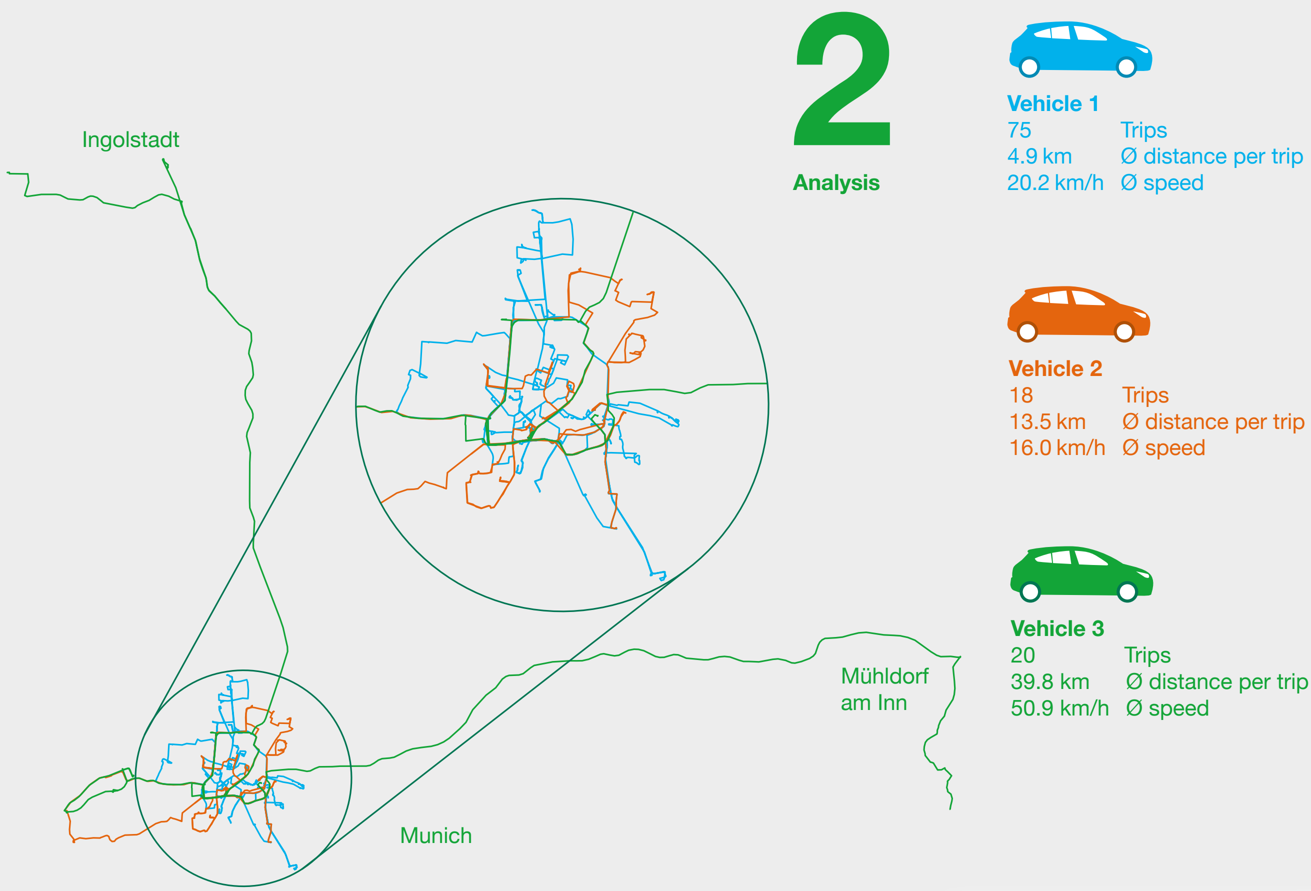
What would happen if we fully embraced electromobility?

“WATE is a brilliant tool for playing out what-would-happen-if scenarios,” as Lennart Adenaw, head of the Smart Mobility Lab at the Chair of Automotive Technology, states. “When it comes to charging infrastructure, in an age when battery capacity and charging performance are improving, there’s a lot of scope for action, which can lead to very different investment plans.”

WATE has been publicly available in various stages of development since 2017. “The feedback has been very positive,” enthuses Adenaw. “A lot of people are amazed about all the insights we can draw from the data.” The findings regarding charging infrastructure are particularly wide-ranging. “We can determine, for example, that a lot of people overestimate the required charging capacity and therefore the number of charging points they need,” says Adenaw. By contrast, the connections for apartment buildings are often undersized, which can result in additional costs if users exceed agreed peak loads. ▷

Graphics: ediundsepp


1
Collecting data
Smartphone
Data logger
GPS
Speed
Acceleration
Data processing
Database
WATE

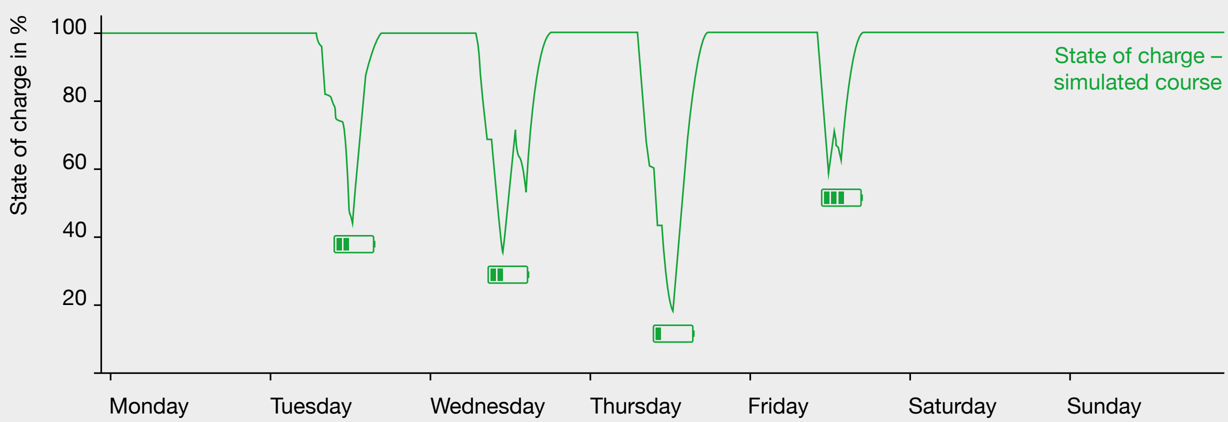

2
Analysis
Vehicle 1
75 Trips
4.9 km Ø distance per trip
20.2 km/h Ø speed
Vehicle 2
18 Trips
13.5 km Ø distance per trip
16.0 km/h Ø speed
Vehicle 3
20 Trips
39.8 km Ø distance per trip
50.9 km/h Ø speed
Ingolstadt
Mühldorf am Inn
Munich

Graphics: ediundsepp (source: TUM)

Suitable for numerous research purposes

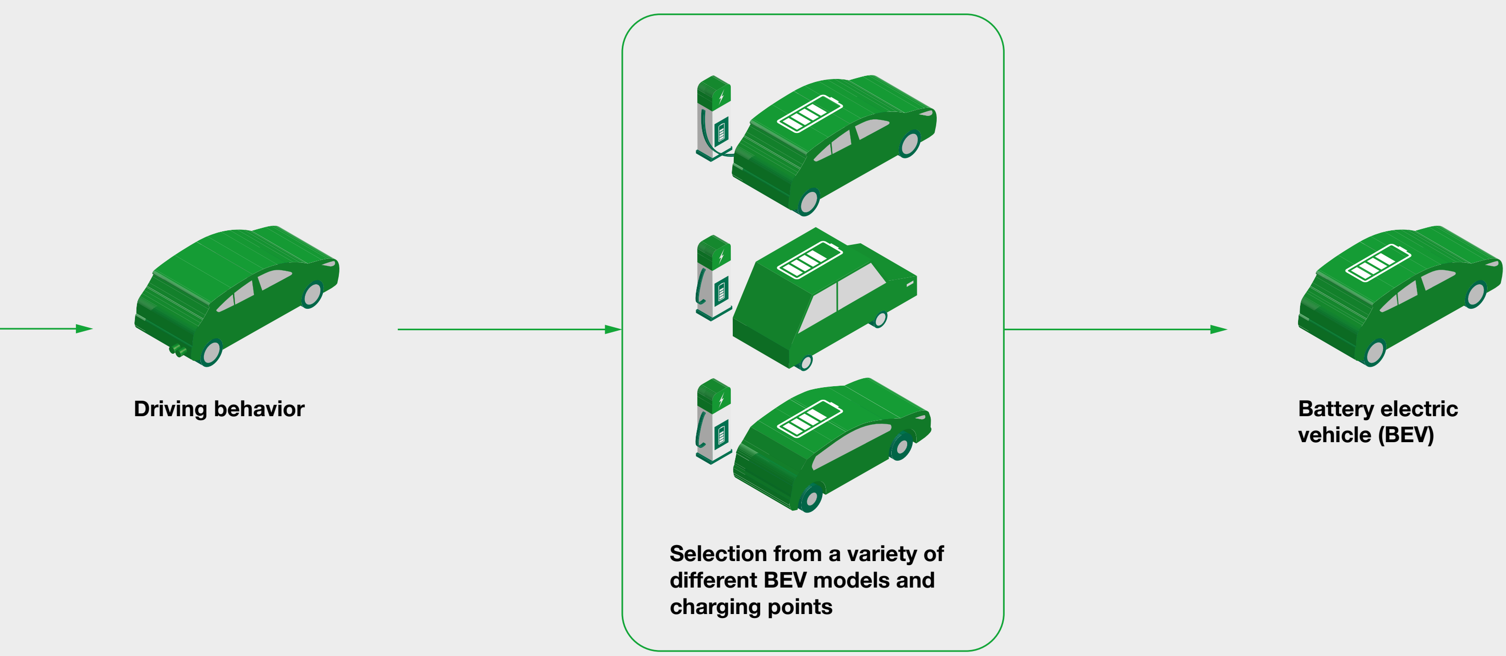
Not only is the analysis tool useful for the general public, it also assists in research and is available to fellow staff at the TUM Chair for use in their projects and dissertations. The tool was developed in its entirety at TUM, with numerous doctoral candidates, student assistants, and partners from industry and the public sector all playing a part, including the City of Munich and the Chamber of Industry and Commerce for Munich. “Its development required and continues to require wide-ranging knowledge from several specialist fields, from classic automotive engineering to the analysis of complex data volumes,” underscores Adenaw. WATE has already gathered data on seven million kilometers of journeys – and is now being used in many other projects. For example, it has been deployed by the electromobility consultants at the Chamber of Industry and Commerce for Munich. In addition, the data loggers are in use in the vehicles of private individuals, tradespeople and logistics specialists, as well as in prototype vehicles in Africa. As a result, the volume of data collected is growing – and so too is knowledge of electromobility around the world. ■

Gitta Rohling



3

Simulation



Shrink Your **Travel Footprint**

Whether on an airplane or a visionary high-speed Hyperloop system, one key question remains: Will future transport allow us to travel without burdening the environment? An interview with Agnes Jocher, Professor of Sustainable Future Mobility at TUM.

Domestic flights within Germany produce five times as much greenhouse gas as trains traveling the same route, according to Germany's Federal Environment Agency. Can I actually travel by airplane with a clean conscience anymore?
That is, of course, a question that each individual can only answer for themselves. However, the following question could help your decision: Can I avoid traveling, reduce my travel, or compensate for it by contributing to climate-protection projects? There are various actors carrying out such projects – and I'd like to mention the 'Gold Standard' program for climate interventions.

The most effective means of reducing the CO_2 emissions of aircraft is switching to alternative fuels. What exactly are you researching on this topic?
We're researching two alternative fuels. The first type is drop-in fuels. These fuels have been given this name because they're similar to conventional kerosene and can be used without the need for significant changes to airplane turbines. They avoid CO_2 emissions throughout their life cycle but still produce soot particles that have an effect on the temperature of the earth's atmosphere. We still don't understand precisely how these soot particles come about or what their effects are. So, we're using numerical simulations and experiments to investigate the physical and chemical processes of soot formation in combustion processes. We hope this will enable us to predict the type and volume of soot particles and develop reduction strategies. ▷

Gesamter Artikel (PDF, DE): www.tum.de/faszination-forschung-28

Reisen mit Bedacht

D

Können wir in Zukunft reisen, ohne die Umwelt zu belasten? Prof. Agnes Jocher forscht an alternativen Kraftstoffen für Flugzeuge und am visionären Hochgeschwindigkeitszug Hyperloop. □

Link
www.asg.ed.tum.de/en/sfm

Picture credit: Astrid Eckert/TUM

Prof. Agnes Jocher

studied at TUM and gained her doctorate from the Faculty of Mechanical Engineering at RWTH Aachen and Sorbonne University, Paris. She then worked as a post-doc fellow at the Massachusetts Institute of Technology (MIT) in Boston. In a subsequent post at the German Environment Agency (UBA), she was responsible for sustainable aviation fuels. She became Professor of Sustainable Future Mobility at TUM in July 2020.

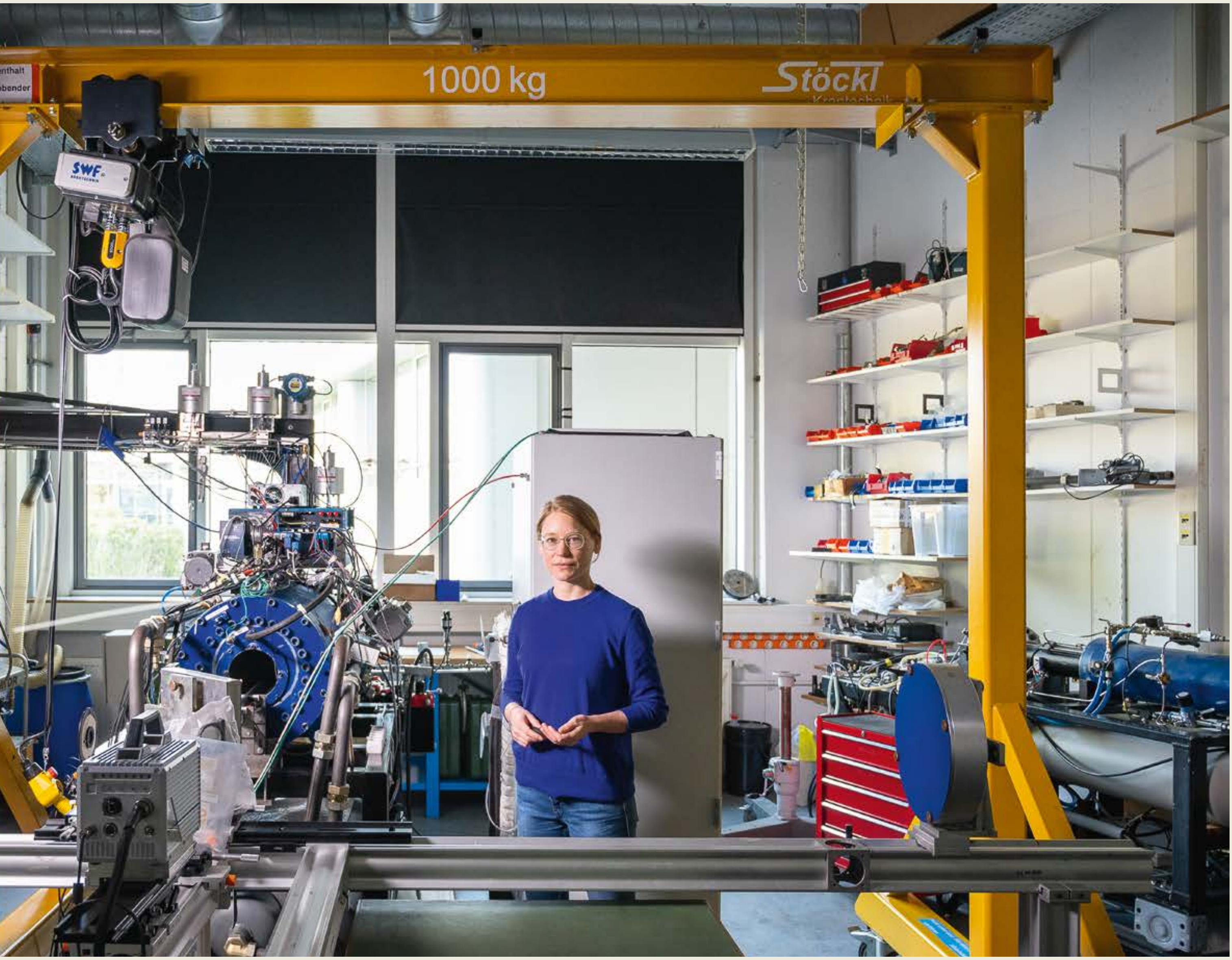
“Within the TUM Hyperloop program, my sub-group is investigating which technical designs might actually be possible.”

Agnes Jocher

The second alternative fuel we’re researching is hydrogen, which does not result in tailpipe CO_2 or soot particle emissions. However, in contrast to drop-in fuels, the use of hydrogen requires significant interventions in airport infrastructure and airplane engines. We’re looking at the question of how combustion chambers can be converted from using kerosene to hydrogen. First of all, we want to research the thermo-acoustic impacts like noise and vibrations on a modular test bench, which we’re currently converting from kerosene to hydrogen. The first prototype aircraft with a hydrogen combustion chamber should take off in the next few years.

A tube with transport capsules capable of traveling at up to 1,200 kilometers per hour: Hyperloop is the vision of Tesla founder Elon Musk. Your professorship is linked to the interdisciplinary TUM Hyperloop program. What is your role in the program?

The TUM Hyperloop program, which comprises eight doctoral candidates and over 60 students, is dedicated to analyzing the technical and systematic feasibility of the Hyperloop. My sub-group is investigating which technical designs might actually be possible. When it comes to the extremely complex levitation and drive systems, this is a crucial, fundamental decision.



Agnes Jocher and her team are researching alternative fuels for transportation that reduce CO_2 and other emissions.

Picture credit: Astrid Eckert/TUM

Hand on heart, is the Hyperloop a realistic prospect?
In our view, it is technologically feasible. The economic, ecological and social practicalities are another matter and are also being examined as part of the TUM Hyperloop program.

The Hyperloop's main drive system is planned to be electric. How sustainable would the Hyperloop be compared to rail travel?
We're still not able to make any valid forecasts as we're only in an early phase of development. Plus, sustainability calculations also need to consider the construction of infrastructure and the Hyperloop's service life.

Can you predict how we will travel in 50 years' time?
I would rather provide a target: I believe that, in the future, we should be able to complete our entire daily routine on foot. Instead of hopping on the Hyperloop to race to work in a neighboring city, our workplaces should be only 15 minutes away. That would be good for the environment – and for our wellbeing. Longer journeys should be the exception and that's obviously when we'll need trains, the Hyperloop and airplanes. This will require coordination with urban developers. Where should we build Hyperloop terminals? How will we connect our cities? We need to consider our answers to these questions very carefully.

■ *Gitta Rohling*

Page 06

Smart mobility is about traveling sensibly and intelligently. In Bavaria, we might even call it ***'gscheit mobil!'***

Prof. Gebhard Wulfhorst

Page 34

The transport network of the future is digital. Will Germany be part of it?

Prof. Alois Knoll

Page 06

Smart mobility is a sensible use of mobility solutions; it is environmentally friendly, efficient and based on forward-looking technologies.

Prof. Miranda Schreurs

Page 50

A crucial requirement of smart mobility is giving autonomous cars the ability to understand the dynamic objects in the environment around them.

Prof. Laura Leal-Taixé

Page 68

Smart mobility means facilitating climate-friendly, attractive mobility through digital innovation.

Ulrike Jehle

Page 06

Smart mobility has three aspects: First, understanding how people get around. Second, improving the quality of air, space and time. Third, preventing unnecessary journeys and increasing the occupancy levels for those journeys that need to happen.

Prof. Markus Lienkamp

Page 60

Our goal is to achieve safer, sustainable and convenient mobility for all citizens.

Prof. Klaus Bogenberger

Page 26

Smart mobility is not about reinventing the wheel but rather putting people's needs at the heart of things.

Ana Rivas

Page 76

Smart mobility uses reliable sources to inform me which mode of transport would be sensible and sustainable for a given journey – thereby making my journey (and me) 'smart'.

Prof. Agnes Jocher

Page 18

By smart mobility, I mean the optimal coordination of the supply of and demand for transportation options.

Dr. Tobias Massier

Page 70

Smart mobility involves a goal-oriented, data-based and open-minded approach to system design and organization; it is making the mobility solutions of the future more resource-efficient, livable and in line with real needs.

Lennart Adenaw

Page 44

Smart mobility utilizes a user-centered portal to offer safe and environmentally friendly mobility services across ***all modes of transport.***

Prof. Matthias Althoff

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Masthead

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Note on the use of language
Women and men have equal rights under Article 3(2) of the German Basic Law. All words and job titles of one gender in this magazine relate to women and men in equal measure.

Note on photos
Some of the photos printed in this issue were taken during the Covid-19 pandemic. During all photo shoots the protection and hygiene rules in force at the time were observed.

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Seeing beyond

Forschung und Entwicklung in der Halbleiterfertigungstechnik

Martins wissenschaftliche Leidenschaft gilt den Oberflächen – eine Präzisionsforschung im Nanometerbereich. Schon in seiner Hochschulzeit trug er zu 25 Veröffentlichungen in internationalen Fachzeitschriften bei. Aber seine Forschung nur auf dem Papier zu sehen, reichte ihm nicht. „Es ist fantastisch mitzuerleben, wie meine wissenschaftliche Arbeit heute die Herstellung von bahnbrechenden Produkten bestimmen kann." Als promovierter Physiker arbeitet Martin jetzt in der Halbleiterfertigungssparte von ZEISS. Der Oberflächen-Spezialist entwickelt Politurprozesse für aktuelle und zukünftige Lithographie-Optiken. An einem Ort, wo wissenschaftliche Ideen die Technologien von morgen ermöglichen.

Erfahre mehr über Jobs in der Halbleiterfertigungstechnik bei ZEISS: **zeiss.de/arbeitenbeizeiss**