

A Global Hub of Knowledge Exchange



A Global Hub of Knowledge Exchange

Technical University of Munich

WHO

WE

ARE

A New Era for TUM



In these turbulent times, all leading universities have one thing in common: either they continue to develop or they fall behind the competition. For the Technical University of Munich – our TUM – this means that, if we want to enjoy even greater success in future, we need to act now by positioning ourselves to cope with the fast-moving challenges of our modern world. In the future, therefore, change will be our only constant!

In this brochure, we outline how and why we are repositioning ourselves – and take you on a thrilling journey into the future of our university. Some 150 years after its foundation, we are implementing an update of TUM's structural DNA. We are reorganizing our internal structure, currently made up of 15 faculties, to form a matrix organization with seven schools and integrative research centers. By explicitly targeting transdisciplinary innovations, we hope to dynamize academic interactivity in our research and teaching and take the university's performance to the next level. The result will be nothing short of a global hub of knowledge exchange.

People are at the heart of our aspirations. Following our reform concept of *human-centered engineering*, we hope to introduce the scientific and technical excellence of TUM into the world of ideas driving modern societies. To achieve this, we will expand the concept of engineering, opening it up to the humanities and social sciences by incorporating society's values, needs and expectations into developing technologies. We will shift from introverted silo mentalities to open, cross-functional and collaborative teams. We will draw on the intelligence of the entire TUM family and mobilize our global partners. And we will supercharge our most powerful driver of innovation: our people!

At TUM, a university with a profile of expertise unmatched

anywhere in Europe, we consider ourselves to be obligated by the fundamental goal of the United Nations. We strive to make a significant contribution to preserving health, treating illnesses, creating a sustainable world, and shaping successful digital transformation. To this end, we conduct research into the very basis of our existence, the molecular codes of life, and the astounding diversity of the natural world. We develop innovative technologies to keep our country healthy and fit to face the future. And we search for groundbreaking solutions to the greatest challenges facing our society.

Being successful in this new decade will require an open culture of innovation and structures in which universities are not merely the first link in the value-creation chain but are instead central players in an innovation ecosystem made up of research institutes, enterprises, technology companies, incubators and start-ups. We will welcome and integrate our curious, open-minded students to join us as central players and a valuable source of new ideas. TUM would be nothing without them.

This brochure also takes a deep dive into a selection of research projects – because, after all, there is nothing quite as exhilarating as science in action. Thank you for joining us on our journey to the future of TUM!

Best wishes,

Prof. Thomas F. Hofmann
President of TUM

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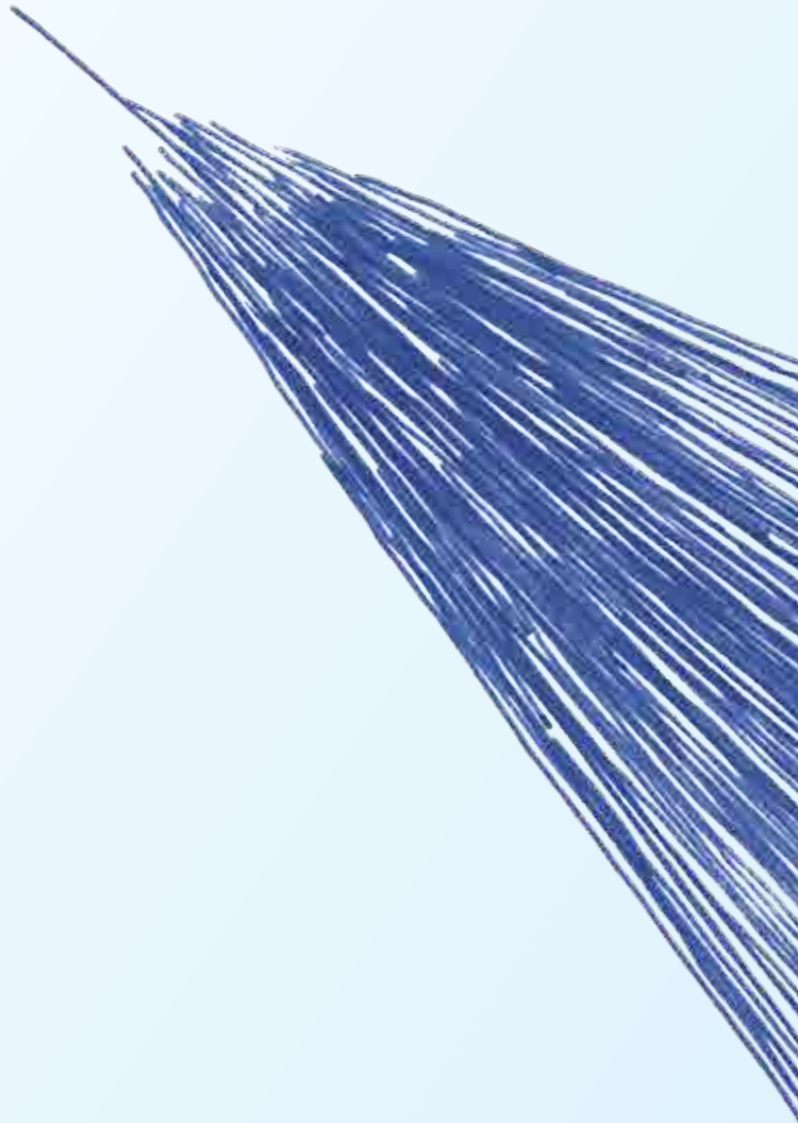
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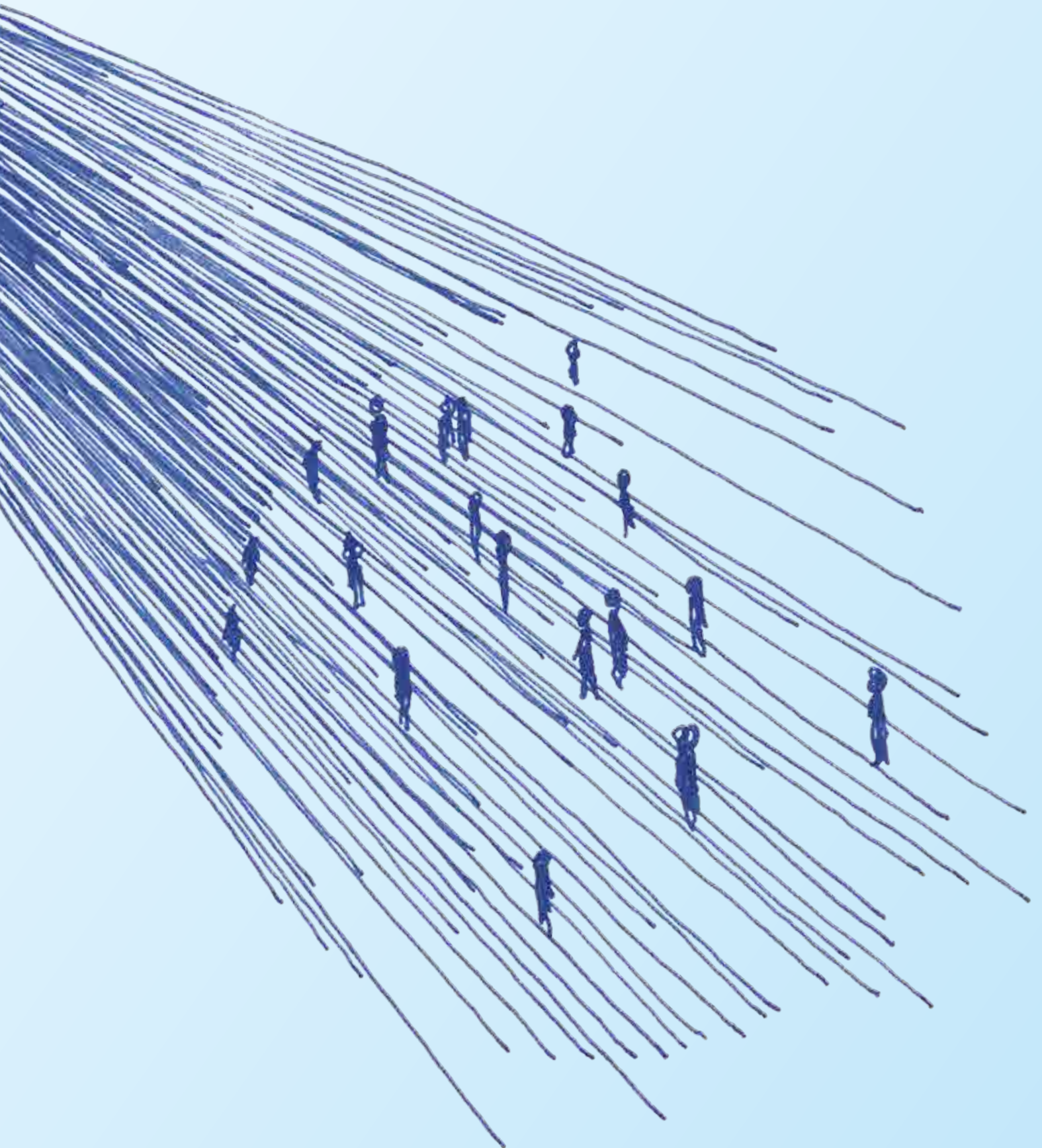




Our Mission

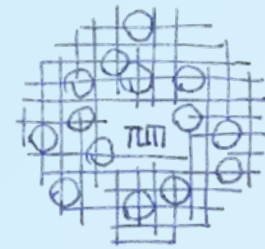
TUM's identity, reimagined

We are committed to making sustainable, innovative progress for the benefit of humankind, nature and society. This principle shapes our actions at TUM.





We break away from mono-disciplinary faculties...



... and create an innovation stimulating matrix structure of schools and transdisciplinary research centers.

Moving forward with curious minds

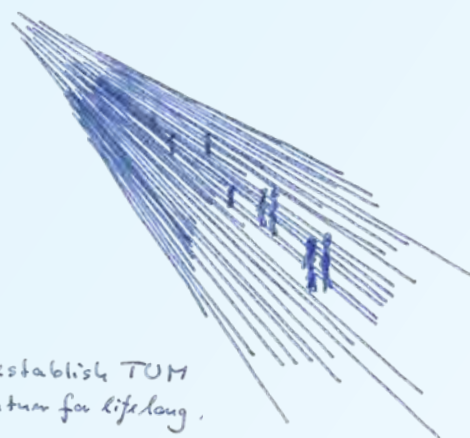
In times of accelerated transformation and flux, change will be our constant. We will learn from our wide-ranging experience and scrutinize the consequences of our actions every single day. We will home in on new challenges and seize promising opportunities to promote the sustainable development of scholarship, ecology, the economy, health, and social relationships – in turn generating joy and motivation and delivering high performance.

Teams, not silos

We will only be able to gain a better understanding of human decision-making processes if we are ready and willing to connect competences in the fields of data science, psychology, neuroscience and economics. We will only be able to predict regional conflicts more accurately if we combine the tools and knowledge in the fields of political science, climate and environmental research, geodetics, social networks and artificial intelligence. And we will only be able to tailor the functionality of technical systems more effectively to human needs by successfully integrating social sciences and Design Thinking methods in innovative engineering processes. This means that, as well as specialists who drill deep into their core disciplines, we will also increasingly need system architects in future. These are individuals capable of exercising skill, foresight and integrative leadership to unite the individual strengths of different disciplines and schools of thought to create an integrated system. In order to improve our efficacy, we are reorganizing our internal structure, moving from a faculty-based system to a matrix organization that promotes innovation, made up of schools, departments and interdisciplinary research centers. In doing so, we aim to convert strategic development potential into innovations with greater efficiency, accelerate the foundation of spin-offs, and improve our operational agility to ensure we are fighting fit to face the future.



We align our research, innovation and education processes to the values and needs of society ...



... and establish TUM as a partner for lifelong learning.

A focus on people

Biologization, digitalization and artificial intelligence are increasingly ubiquitous; their influence now extends to every area of our lives. This makes it all the more important that we reflect on the consequences of our actions at an early stage and examine all social, economic, ecological, political and ethical implications of new technologies – already in the course of their development. In line with our mission of *responsible research and innovation*, we are aligning our research and innovation processes with the values, needs and expectations of society. We pursue innovations not for the sake of technological progress but for the good of humankind. In future, the principle of *human-centered engineering* will pervade our research, innovation and teaching.

A culture of lifelong learning

The world of work is changing in great leaps and bounds. By tomorrow, many of the technologies we learn to use today will have become yesterday's news. Future graduates will change jobs more frequently than was the case for previous generations. At the same time, their careers will be longer, up to almost half a century.

Having this in mind, our teaching will focus on developing competence profiles to enable our students to succeed in the jobs market of the future. We will also continuously develop our teaching concepts and learning tools, encouraging our talented students to identify their individual potential – and then helping them to fulfill it. In addition, we will equip them with the skills they need to shape innovative progress for the good of humankind, nature and society; with outstanding scholarship and an ability to make interdisciplinary connections; with entrepreneurial courage and sociopolitical tact; with responsibility and an awareness of values; and with a lifelong attitude of cultural and academic openness. In times of accelerated transformation and flux, we shoulder social responsibility and, as a partner for lifelong learning, seek to ensure the continued professional success of our own staff, our alumnae and alumni, plus specialists and leaders from the fields of business, politics and civic society, by offering continuous training and education firmly rooted in science.

»We Are Building a Global

Hub of Knowledge Exchange«

An interview with TUM President
Prof. Thomas F. Hofmann





TUM is undergoing a fundamental reorientation. In this interview, TUM President Prof. Thomas F. Hofmann explains why now is the right time for the university to reinvent itself – and the tremendous opportunities this could open up.

Turn to page 21 for more about *human-centered engineering*.

Prof. Hofmann, simply put, the United Nations' Agenda 2030 aims to make a better future possible for humankind. In keeping with this, TUM has committed to promoting sustainable innovative progress. In your editorial, you write about the search for “groundbreaking solutions to the greatest challenges facing our society”. Exactly what areas are you focusing on?

At a very fundamental level, our focus will always be on people. *Human-centered engineering* is the maxim that guides our research, innovation and teaching. This is also why we are integrating social sciences and the humanities more closely into our portfolio at TUM. This notion of *human-centered engineering* describes engineering with a broader mindset; in future, we will incorporate the values, needs and expectations of society when developing new technologies. To my mind, greater recognition of society in the context of increasingly complex technologies will be a critical factor in Germany's success as a location for innovation. Social sciences and the humanities, with their capacity to facilitate theoretically

and historically informed reflection, therefore represent an essential element to be integrated in future research and innovation processes. To this end, we will massively expand technically oriented areas of the humanities, social sciences, political science and economics, integrating them into our research and teaching in the fields of engineering, natural sciences, life sciences and medicine. We will also incorporate creative aspects, however, such as Design Thinking methods, as part of our holistic approach to innovation. This means that, in future, we will tackle the challenges facing society based on a disciplinary grounding but with the interdisciplinary connections and flexibility to allow us to effectively integrate creative, functional, political, social, economic, ecological and ethical implications. In doing so, we will create a new foundation for trustworthy, socially acceptable and sustainable innovations.

Doctors and IT specialists effectively speak different languages; a sociologist will use different methods to an engineer. When specialists from different disciplines work together, it can quickly lead to misunderstandings. How will you enable your students and researchers to work successfully across disciplines?

By honing their ability to connect the methods, tools and knowledge of different disciplines where necessary. The greatest scientific successes of the future will not be achieved through deliberations in quiet solitude. Even today, innovations are rarely achieved within the confines of isolated disciplines. The future, therefore, belongs to those who manage to combine academic talent

from different disciplines more efficiently than before to form collaborative alliances, which are a critical success factor.

Some 150 years after its foundation, the DNA of TUM is to be given an “update”, as you put it. In your editorial, you write: “We are reorganizing our internal structure, currently made up of 15 faculties, to form a matrix organization with seven schools and integrative research centers”, explicitly targeting transdisciplinary innovations. What is behind this move?

Above all, we are seeking to dynamize academic interactivity in our research and teaching while simultaneously taking both our agility and our performance to the next level. This goal is also served by the **TUM Innovation Networks**. With this new format of collaborative research, we want to bring together academic talent from different disciplines more efficiently than ever before through a bottom-up approach, thereby encouraging them to adopt visionary research approaches, explore genuinely uncharted scientific territory and test out the development potentials – before anyone else has dared to do the same.

And what does this mean for your students?

By adopting our new matrix structure, we are also responding to the need to modernize our teaching and implementing a historic reform, moving from one-size-fits-all education towards more personalized, flexible programs of study capable of meeting the evolving demands of global job markets, as well as the talents and motivations of our students.

»By aligning our mission with the values and expectations of society and the needs of the natural world, we are creating the basis for trustworthy, socially acceptable and sustainable innovations.«

PROF. THOMAS F. HOFMANN

We see students as central players in this context and are actively integrating them as a valued source of ideas, such as through the **TUM Future Learning Initiative** and a recent introduction, the **TUM Presidential Student Lunch** which will be held on a regular basis. In doing so, I am intensifying a straightforward, direct exchange with students from all disciplines – the people who matter most to TUM. Students are our customers; they are the beating heart of our university and shape our shared future. It would, therefore, be utterly foolish to fail to take students' opinions into account. In order to ensure that students enjoy a unique learning and life experience at TUM, I believe that interactive and trusting relationships between teaching staff and students are every bit as important as a practiced culture of appreciation and an open exchange of opinions and ideas with the younger generation.

You say you want to create a global hub of knowledge exchange. What will this look like?

Technologies will undoubtedly be decisive if the triumphal march of digitalization, biologization and miniaturization is to continue. Despite this, however, we perceive people as the most powerful driver of innovation! What matters, then, is to replace introverted silo mentalities with collaborative networks and, by working in cross-functional teams, to mobilize the intelligence of the entire TUM family and our global partners wherever possible. Through our **TUM. The Open University Initiative**, we are turning TUM into a creative space that enables bright minds from the worlds of science, business, politics and society to gather and pool their talents, exchange ideas, inspire one another,

challenge one another, upskill and collaborate in promising fields of innovation, with the common goal of shaping the world of tomorrow. An open-minded exchange between people with different talents and respectful, appreciative cooperation are key to our future mission, as is an openness to lifelong, continuous learning.

What exactly does lifelong learning mean for your alumnae and alumni?

In times of accelerated transformation and flux, our alumnae and alumni will change jobs more frequently in future than was previously the case. Although professional careers are likely to last longer in future, dynamic technological leaps forward mean that the competences acquired at university yesterday will no longer be sufficient to remain competitive on tomorrow's jobs markets. I am convinced that successful alumnae and alumni will remain students for life! As a socially responsible university, we regard ourselves as duty-bound to offer educational opportunities rooted in science, thereby assisting our alumnae and alumni to continue to learn and upskill alongside specialists and leaders from the fields of business, politics and society. TUM will become a lifelong education partner to our alumnae and alumni, helping them to keep up with the rapid pace of technological development. As an important structural measure of our TUM AGENDA 2030, we are pooling all of our programs in our **TUM Institute for LifeLong Learning (TUM IL³)**.

Society, however, is placing even greater demands on us. What is the significance of sustainability for you?

Sustainability is one of **our central guiding principles**. In future, we will increasingly have to be gauged against what we do to promote sustainability in our society – at economic, social and ecological levels. Of course, we will expand our research and teaching activities in modern agricultural and plant sciences, bioeconomics and the fields of energy, mobility and climate research, searching for innovative solutions to promote the sustainable development of our planet. However, sustainability must also become a more integral element of our own organizational and campus development. Future generations of stu-

dents will prefer to study and work at a university that keeps its own greenhouse gas emissions and environmental impact as low as possible – by saving energy, producing some of our own energy, and improved resource efficiency. These very considerations were incorporated into the concept for TUM's Friedrich N. Schwarz Research Station, which allows us to explore the Alpine ecosystem and trial new forms of scientific teaching. This sustainable wooden building is situated at an altitude of 1,262 meters above sea level in the forest above Berchtesgaden and predominantly functions autonomously thanks to rainwater

For examples of projects in our fields of research, see page 42 onwards.



treatment, biological wastewater treatment and photovoltaic systems. Given its significance, we have anchored the topic of sustainability at the heart of our university development in the form of the **TUM Sustainability Office**. We want to reflect self-critically on what we do, highlight where action is required, and implement specific projects and effective measures so that our TUM develops more sustainably – across all levels: teaching, research, innovation, administration and, of course, the development of our university locations!

How has the Covid-19 pandemic affected collaboration?

The pandemic might well have distanced us in physical terms, but it has brought our university closer together as a community. Thanks to the tremendous dedication and creativity of all our teaching staff, TUM's experts in the field of university teaching, and with the help of new, creative formats, we have scaled up digital teaching university-wide and become a pioneer of electronic examinations in Germany. The coronavirus crisis has had a catalytic effect at TUM! Our students, too, have shown outstanding dedication. More than 500 student helpers have completed training to become "e-Scouts" and can now assist teaching staff in editing videos, holding online tutorials, and managing discussion forums and chats. Yet, this new community spirit extended far beyond teaching: with more than 275 research projects on topics related to Covid-19, we built new and interdisciplinary bridges in the blink of an eye. In addition, by facilitating an agile,

interdisciplinary and transsectoral exchange between the worlds of science, business and politics, the new TUM THINK TANK has assisted policy and decision makers in Bavaria by providing fact-based recommendations for actions to overcome the immense challenges brought about by the pandemic, as well as developing targeted measures for future crises.

How can TUM ensure that the valuable results of its research are applied even more effectively in the business world?

In times of change, the classic university system of concluding knowledge transfer agreements, thereby allowing research results to be used through R&D collaborations, patents and licenses, lacks the necessary dynamics. In order to be successful, we require an open culture of innovation and promotive structures in which universities are not merely the first link in the value-creation chain, but are instead players in an innovation ecosystem made up of research institutes, enterprises, technology companies, incubators and start-ups. Everyone should share their valuable expertise and experience, collaborate trustingly and effectively, and pool their resources in the fields of talent management, professional development and social participation as a future element of added European value. It will make our university and the companies with which we engage more flexible and adaptive, enable us to predict new developments at an earlier stage, and align envisaged innovations with the values, needs and expectations of society. In this lived symbiosis, universities will benefit from the permanent

»Only when we understand what matters to our students, what motivates them and what their needs are, and only when we appreciate their creative proposals and outlook for the future, will we be able to help them achieve their full potential.«

PROF. THOMAS F. HOFMANN

interactions between the complex challenges and issues facing business and society; they will also continue to develop through cooperation with external practice partners in research and in teaching, with a future-facing focus. Students will learn to understand new, practical interrelations and can apply and deepen their knowledge to generate value, while companies benefit from these talented young minds and their creativity and thereby gain competitive advantages. This type of symbiosis requires strategic, intimate and trust-based long-term collaboration between the university and companies – which is exactly what

our **Industry-on-Campus Strategy** aims to achieve. We have already agreed a number of multi-year partnerships: the DRÄXLMAIER Group, GE Additive and SAP SE already have a presence on our Garching campus, with Siemens and Oerlikon to follow in the near future.

How can TUM use start-ups to further improve our contribution to our country's economic development?

Supplementing our **Industry-on-Campus Strategy**, as part of the TUMentrepreneurship program,



»If we want to be even more successful in future, we need to act now, positioning ourselves with the agility, dynamics and transformational power required to effectively tackle the fast-shifting challenges of our modern world.«

PROF. THOMAS F. HOFMANN

we are working with the **TUM Entrepreneurship Research Institute** and our affiliated research institute **UnternehmerTUM** to provide enduring support for the establishment of growth-focused and technology-based companies – from the ideation phase through to their foundation and successful market positioning and into the growth phase. In doing so, we have become Germany's leading higher education institution for start-ups. We bring about 70 to 80 tech start-ups to market each year, while TUM start-ups attracted more than €1 billion in investments in 2019. In conjunction with **UnternehmerTUM** and with the aim of becoming a European leader in the foundation of growth-oriented technology-based start-ups, we have started supporting the university with a network of innovation centers and incubators. Known as **TUM Venture Labs**, these centers are aimed at developing deeptech start-up families around selected technological focal points. They provide the necessary development environment – from the technical and social infrastructure to entrepreneurship coaching and support from networks of businesses and investors.

All of these changes represent a major task. What went through your head on September 30th, 2019, when your predecessor draped the Chain of Office around your neck during the handover ceremony?

Great joy – and no small amount of reverence and respect at the prospect of taking on this enormous task from the former President, Wolfgang A. Hermann.

How will TUM manage to accomplish this unique reorientation?

By self-critically reflecting on our actions every day and not becoming boastful; instead, we will take the ideas of each and every member of our TUM family into account and learn from our experiences. By ensuring that all of us – from scientists and researchers to every science-facilitating member of our university's administration – keep an open mind in these changing times. Instead of acting as separate halves of the same brain, we need to be closely linked, thinking and acting together as ONE TUM. By mustering great agility in addressing the ever-evolving challenges we are faced with and seizing promising opportunities to promote the sustainable development of humankind, nature and society. In doing so, we will generate joy and motivation and deliver strong performance. I feel confident that, building on the traditions and achievements of our university to date, we will build a successful future together.

The Trans- formation

From a faculty structure to a matrix organization

The fundamental structure of TUM is evolving from a faculty-based system to a matrix organization. This all serves a greater goal, namely the systematic networking of experts and students in all specialist areas, in line with the future-focused TUM AGENDA 2030. An overview.

In this era of digitalization and biologization – and in the midst of the Fourth Industrial Revolution – we are faced with unprecedented international competition. In these times, the worlds of science, business and society are transforming at unprecedented speed. Building on its solid spectrum of performance and services, TUM is pursuing its TUM AGENDA 2030, thereby building on a wide-ranging, enduringly effective dynamic of regeneration as it strives to boost the scientific innovative power and coherency within its university family. In doing so, we are accelerating TUM's transformation from a subject-focused institution to a purpose-driven, system-oriented university of highest impact.

What are the guiding principles of the TUM AGENDA 2030?

1 We are creating an internal structure that promotes innovation

Faculty-specific teaching and research programs are no longer able to keep pace with the need to develop systemic skills to compete in future. Efficiently creating system-integrative cooperative alliances is a decisive success factor when it comes to exploring as yet uncharted, interdisciplinary areas of science. It is for this reason that, after more than 150 years, we are transforming our internal structure – moving from 15 additively augmented faculties to a matrix organization that will promote innovation. We are creating seven schools with departments covering the entire portfolio of major scientific domains, which will serve to form an identity and provide calibration within international scientific communities. Situated at the interfaces between these schools, **Integrative Research Centers (IRC)** will address system-wide challenges and wide-ranging, future-focused issues through transdisciplinary approaches to research and teaching.

2 We are fostering collective creativity and transdisciplinary teams

By establishing the **TUM Institute for Advanced Study (TUM-IAS)**, TUM has created a gateway to the world of interdisciplinary cutting-edge research. The **Integrative Research Centers (IRC)** represent a new method of focusing intellectual power in innovative fields (such as energy

systems, sustainability and bioengineering) in which visible success in the international arena can only be achieved through inter-school and mission-driven collaboration. Examples include the **Munich School of Robotics and Machine Intelligence (MSRM)**, which focuses on machines capable of acting autonomously in the fields of health, work and mobility, as well as the **Munich Data Science Institute (MDSI)** – a center of excellence for multidisciplinary, data-driven research under the overarching topic of *computational science and engineering across scales*. The MDSI is focused on theoretical principles and fields of application in which the use of data sciences and machine learning can be expected to deliver transformative developments, such as personalized medicine, material sciences, and digital planning and construction. The **TUM Design Institute** pursues a new approach with the aim of adding a new dimension to creative aspects and Design Thinking at TUM by perceiving them as consistent companions of engineering research and education, in constant feedback loops with new technical scopes of action. Transdisciplinary teams, collective creativity, new ideas – and the freedom to pursue them: in order to help high-risk yet promising areas of innovation reach a critical mass, **TUM Innovation Networks** offer significant flexibility to activate and explore new connections between schools (Emerging Fields Policy). They investigate pioneering research questions as a success-critical basis for new, competitive cooperative projects, such as Clusters of Excellence and Collaborative Research Centers.

3 We are integrating humanities and social sciences

We are significantly expanding our portfolio of technically-oriented humanities and social sciences in the new **School of Social Sciences**. In doing so, we will allow these research domains to build their own profile while, at the same time, giving them sufficient integrative valency and educational capacity to benefit the natural, engineering, life and economic sciences as well as the field of medicine, therefore describing their overall strategic context at TUM – as the leitmotif of our mission of *human-centered engineering*. This integrative approach, which is aligned with the values, needs and expectations of society, tackles the major challenges of our time by combining disciplinary foundations with the interdisciplinary flexibility to allow creative, functional, political, social, economic, moral and ethical implications to be taken into account. This lays the foundations and provides the academic excellence for our future mission of *responsible research and innovation*, while also providing a third dimension to our entrepreneurial spirit.

4 We are instigating a paradigm shift in teaching

We have set our sights on giving our students an effective education that will enable them to take responsibility for shaping change processes in society. Our new matrix structure also allows us to take actions where required in terms of modernizing our teaching. In light of the changing times and under the leadership of the **TUM Center for Study and Teaching**, we are accelerating the transition from size-fits-all education towards a more personalized mix-and-match range of studies with the flexibility to meet the shifting requirements of global job markets. We will increasingly gear our programs of study to the competence profiles required for future professional careers (*TUM Professional Profiles*), but will also optimally address our students' specific talents, their individuality and their motivation. Our courses of study will, of course, retain their academic depth and rigor; however, we will discard outdated content, break down traditional boundaries between disciplines and leverage innovative, digital education technologies (**TUM EdTech Center**) to effectively convey new knowledge to students. By implementing interdisciplinary, problem-based, team-project formats, we aim to teach students from different fields to approach complex challenges collaboratively, creatively and flexibly, and to activate their inventive curiosity and entrepreneurial spirit as "studentpreneurs". We are also integrating the humanities, social sciences and economics in order to develop a new attitude based on responsible thoughts and actions. In doing so, we aim to support our students as they forge their identities and sharpen their awareness of values. This new on-campus learning experience will undoubtedly require a long-term change in building infrastructure, moving away from regarding buildings as housing disciplinary strengths and instead seeing them as more flexible, interactive spaces that should serve to stimulate new ideas, creativity, critical thinking and collaboration.

5 We are connecting people across disciplinary, institutional, cultural and generational boundaries

When it comes to developing innovations, technologies are decisive – but far from the only factor. It is also important to supercharge the most powerful driver of innovation: our people!

Consequently, we are deepening our connections with schools in order to foster pioneering spirit for science and technology at an early age in future generations. We will connect schools with the individual talents, youthful enthusiasm and unquenchable thirst for knowledge of our international student body, as well as the specialist expertise, creativity and wide-ranging experience of our teaching staff and contributors – across disciplinary and cultural boundaries. For this reason, we are further deepening our collaboration with strong partners from the world of business and applying the results of our basic and applied research in market-oriented innovation processes and socially relevant products and technologies. We are convinced that integrating young founders in an inspiring scientific and economic environment is the most promising way to ensure that their groundbreaking ideas have an enduring impact on social change. By assisting in the foundation of growth-oriented, technology-based start-ups, we are striving to create a Europe-leading innovation ecosystem. This is why we network with our alumni, who act as ambassadors with a global sphere of influence, as well as our seasoned, worldly-wise emeriti and numerous individuals who significantly extend our reach through their actions as our collaboration partners, patrons, sponsors and supporters. We are therefore pursuing interdisciplinary approaches to integrate citizens in development processes for innovation and education; we aim to establish an intensive dialog with political actors and the general public. In doing so, we are solidifying our determination to regenerate and are shaping the world of tomorrow – together.



→ **Prof. Diébédo Francis Kéré**

During his studies at the Technical University of Berlin, Prof. Diébédo Francis Kéré (born 1965) returned to his native village of Gando to build a primary school there, using local materials and techniques and encouraging the community to participate in the project. In 2004, the work won the Aga Khan Award for Architecture. It was swiftly followed by further school buildings in Gando and many other places. At the same time, the young architect founded the Kéré Foundation and his own architecture office in Berlin, receiving prestigious awards and prizes in acknowledgement of sustainable construction that contributes to society. Kéré collaborated with Christoph Schlingensiefel to develop Opera Village Africa in Burkina Faso. Today, exhibitions showcase Francis Kéré's buildings and design principles. He has also spent time teaching at Harvard (US) and Mendrisio (Switzerland). Kéré took up his role as Professor of Architectural Design and Participation at TUM in October 2017.

The New TUM

Teaching Research

TUM EdTech Center

TUM Schools

Computation, Information and Technology

Engineering and Design

Natural Sciences

Life Sciences

Medicine and Health

Management

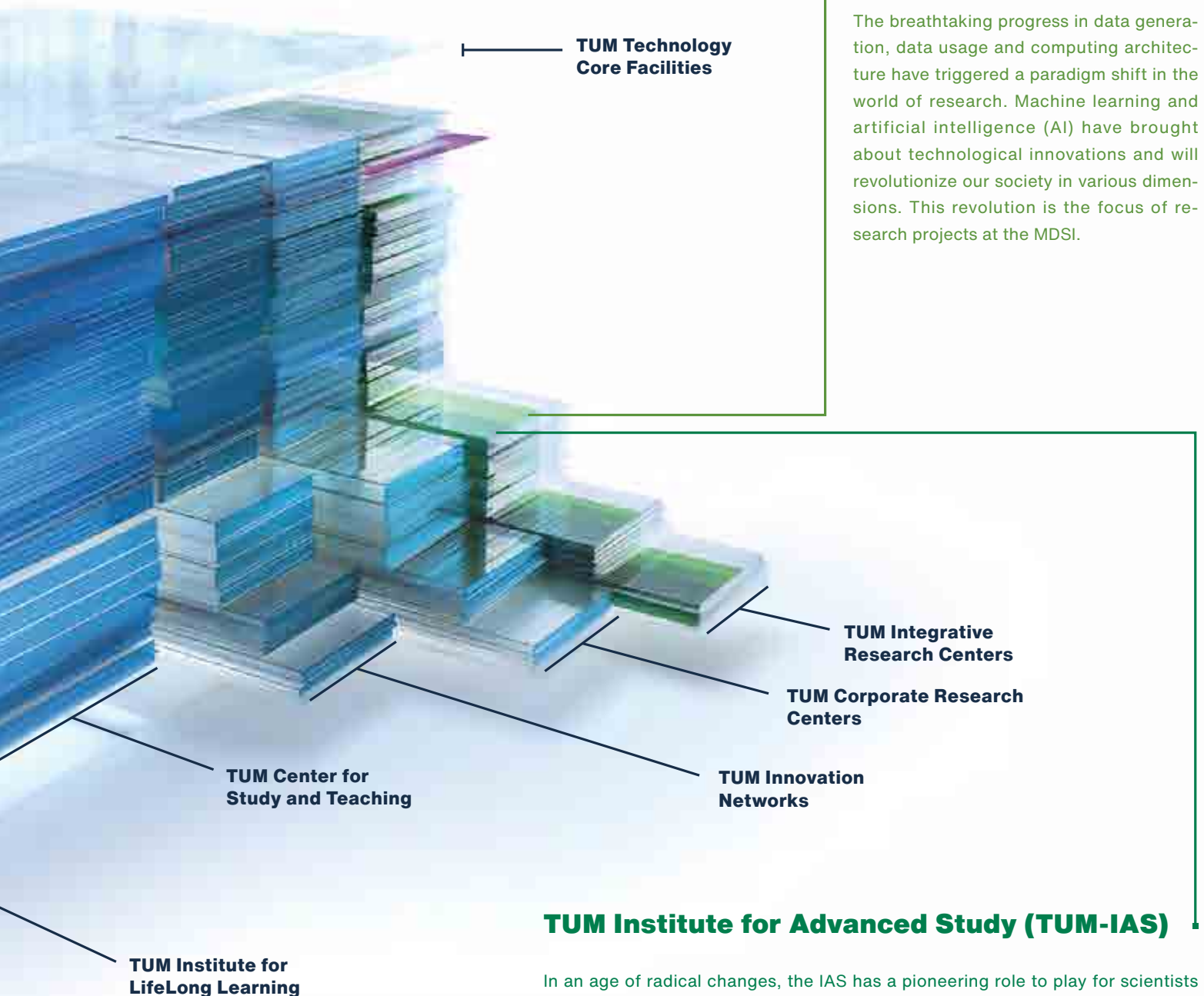
Social Sciences

TUM EdTech Center TUM Technology Core Facilities



Alumni and Partner Network

TUM-IAS Explorative Workshops



Munich Data Science Institute (MDSI)

The breathtaking progress in data generation, data usage and computing architecture have triggered a paradigm shift in the world of research. Machine learning and artificial intelligence (AI) have brought about technological innovations and will revolutionize our society in various dimensions. This revolution is the focus of research projects at the MDSI.

TUM Institute for Advanced Study (TUM-IAS)

In an age of radical changes, the IAS has a pioneering role to play for scientists and researchers. "Risking creativity" is the motto of the IAS, which serves as a flagship for international cutting-edge research. Its fields of research cover a broad spectrum of innovative and interdisciplinary areas. The IAS offers international figures at the cutting edge of science and industry not only creative freedom but also – subject to certain guidelines – space for speculative, high-risk projects.

www.ias.tum.de



Our Open

Net- work

How TUM will systemati-
cally promote exchange in
future

Zaim Sari, business informatics student
and former student representative in the
Senate and within the university

Listening to each other, researching together: how TUM will promote interdisciplinary exchange in future – and thereby turn its vision of a global hub of knowledge exchange into reality.

In the future, we at TUM will pursue a collaborative approach to innovation, free from the confines of disciplinary, institutional and conceptual boundaries. To this end, we will inspire, foster and develop talented minds, embracing their diversity and helping them to become responsible, open-minded individuals. We will equip them with the skills they need to shape innovative progress for the good of humankind, nature and society; with outstanding scholarship and technical expertise; with collaborative intelligence and the capacity to make interdisciplinary connections; with entrepreneurial courage and sociopolitical tact; and with a lifelong attitude of cultural and academic openness.

Why are we doing this?

The modern world is changing rapidly and tempestuously, in many different respects.

New technologies: We live in an age of exponential technological developments; much of what is taught at universities today will become outdated tomorrow.

New worlds of work: Our future graduates will switch employers more frequently than has been the case to date; they might even find themselves employed in sectors of the economy that do not even exist yet. At the same time, their careers will be longer, probably spanning up to fifty years. In addition, future employees will experience at least two knowledge revolutions in the course of their professional lives.

New challenges: Silo mentalities limited by disciplinary boundaries cannot yield innovative solutions to the complex and dynamically shifting challenges in our networked, fast-moving world. Such solutions demand an interactive amalgamation of knowledge and tools from different disciplines and departmental cultures.



Dr. Carolina Olufemi,
sports scientist and
women's representative



Ana Hernández Chamorro,
architect

What does this mean for university education?

Let's look at a few examples of what our students' future working day might demand of them.

In the future, realizing complex, large-scale construction projects will require civil engineers to master new digital key competences for model-assisted project planning and execution, while simultaneously being able to incorporate a wide range of environmental considerations in their plans along with the interests of local citizens. In order to better understand human decision-making processes, psychologists will need the capacity to combine their competences with those of specialists in data science, social sciences and economics. If political scientists are to predict regional conflicts in world affairs with greater accuracy, they must be in a position to effectively combine their skills with new insights from climate and environmental research, geodetics and social networks, and make effective use of the potential of machine learning and artificial intelligence. The digitalization of medical diagnosis, therapy and prevention across all levels involving the use of big data, machine learning and artificial intelligence will require future medical specialists to tightly intertwine their expertise with the fields of informatics, information and communication technologies, imaging procedures and augmented reality applications. Ensuring that innovative hardware and software systems provide excellent user experience – a critical factor in their success – will require computer scientists to link their expertise with psychological, neurological, creative and economic competences. Whatever their field of employment, our future graduates will have to demonstrate increased willingness to engage in lifelong learning. In times of accelerated change, our graduates will be constantly challenged to expand their horizons beyond their core discipline, borrowing technologies, tools

and methods from other disciplines and integrating the groups of peers they need to achieve their goals.

How will you make this hub of knowledge come alive?

We are developing TUM into a creative and stimulating place, where people from different cultures and various organizations from the worlds of science, business, politics and society can come together to exchange ideas and inspire one another, challenge one another, upskill and collaborate – all with the common goal of shaping innovative progress for the good of humankind, nature and society. In keeping with the notion of a living generational contract, we will combine the individual talents, youthful enthusiasm and unquenchable thirst for knowledge of our students with the creativity, dedication and wide-ranging experience of our teaching staff, the inventiveness and global impact of our graduates, the worldly wisdom of our emeriti and alumni, and the numerous individuals who significantly extend our reach through their actions as our collaboration partners, patrons, sponsors and supporters. The diversity of our TUM family and a respectful, appreciative culture in which members can open-mindedly exchange ideas and experiences are key to our future mission, as is an openness to continuous, lifelong learning. Ultimately, we believe we have a social responsibility to ensure the continued professional success of our students and alumni through continuous academic education and qualification. With this in mind, we are initiating a transition – from a “one-off degree at TUM” to “lifelong, continuous learning” as a strategic leitmotif of our **TUM. The Open University Initiative.** Through our ongoing exchange and upskilling programs, we are evolving into a dependable anchor point to which graduates can return, time and again, as lifelong students. When they return, graduates can refresh their skills profile and expand it with



Axel Stellbrink,
patent attorney and
TUM alumnus



Prof. Sherry Suyu,
Professor of Observational
Cosmology

new modules, thereby remaining professionally successful against the backdrop of an ever faster-moving jobs market. Together with internal continuous professional development programs for our staff, we are pooling all of our advanced education opportunities under the umbrella of the new →**TUM Institute for LifeLong Learning (TUM IL³)**, thereby creating a unique concatenation of science, technology, business, society and politics. Our strategic partners are also integrated in this vision through our →**Industry-on-Campus Initiative**.

→ **Industry-on-Campus**

By establishing long-term strategic partnerships and through co-localization on our Garching Campus, we are working with leading business enterprises to drive the technology revolution forward. Our development partnership with SAP SE – Germany’s biggest R&D partnership between business and academia to date – is focused on finding innovative technological solutions in the fields of artificial intelligence, machine learning, the Internet of Things, robotics, big data, cloud computing and mobility. We have also founded partnerships with the DRÄXLMAIER Group and GE Additive, while partnerships with Siemens and Oerlikon are set to follow soon.



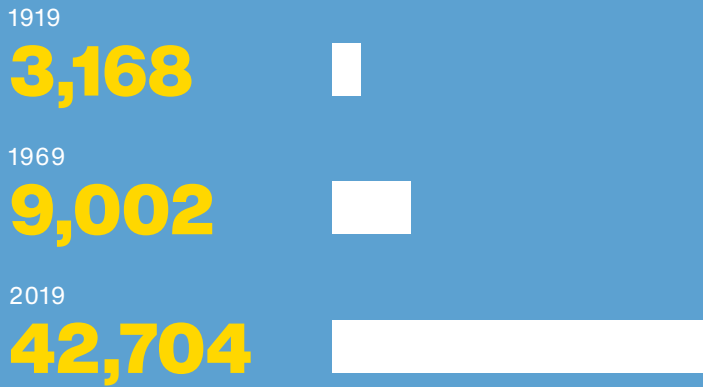
Lion Xylander,
business administration student

TUM Institute for LifeLong Learning (TUM IL³)

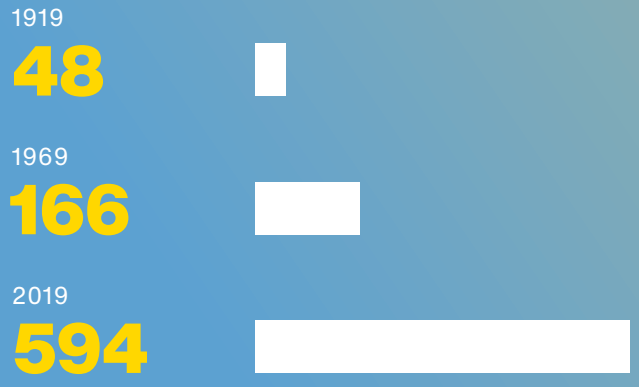
The goal of TUM IL³ is to promote continuous advanced education rooted in science in disciplinary and interdisciplinary fields, such as management and leadership, for international professionals at all career levels from the worlds of science, business and society. Research-oriented, interdisciplinary and networked: By adopting innovative (digital) education formats and integrating the latest content from the technological and natural sciences, TUM IL³ prepares external specialists and managers to overcome current and future social challenges both responsibly and effectively.

www.tum.de/en/lifelong-learning

Students



Professorships



2

German Future Prizes awarded to researchers and alumni

7

Humboldt Professorships (as of November 2019)

135

ERC Grants

22

Leibniz Prizes

17

Nobel Prizes for researchers and alumni

Successes

Our facts and figures

650
Around
spin-off companies since 1990

Total budget incl. Klinikum: over **1.6** billion euros

50
patent applications in 2019

9,545 graduates in examination
year 2018/19

Over **170** degree courses

32% international students

36% female students

Over **8,900** publications per year

Around **83,000** members in our alumni network

1,103 doctorates conferred at TUM in examination year 2018/19

Figures are up to date as of 2019.

Collaborations

150+

partner universities worldwide

350+

Erasmus partnerships across Europe

■ <10

■ <30

■ >30

partner universities

● San Francisco

● São Paulo



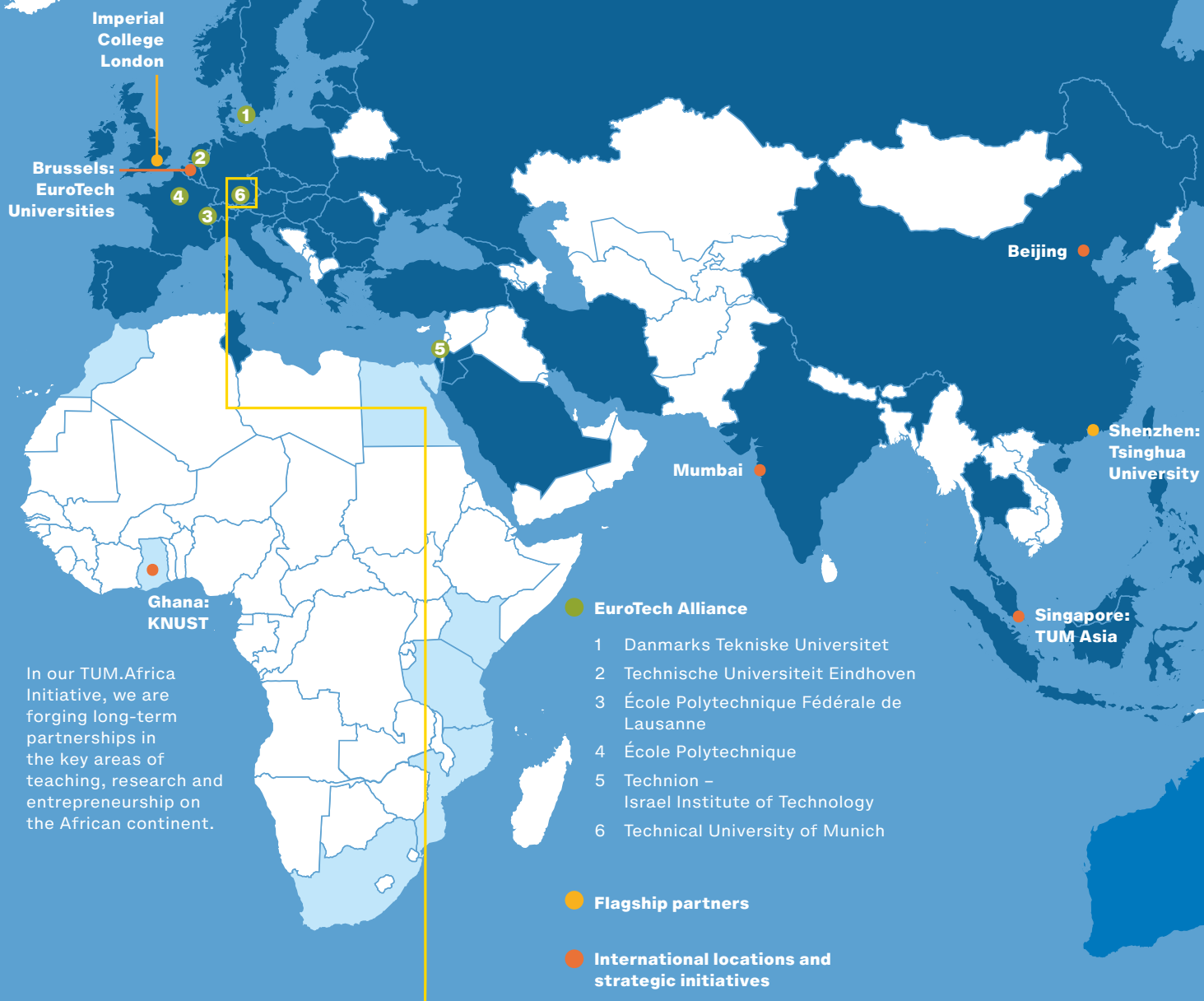
TUM around the world

We have locations on four continents around the globe.

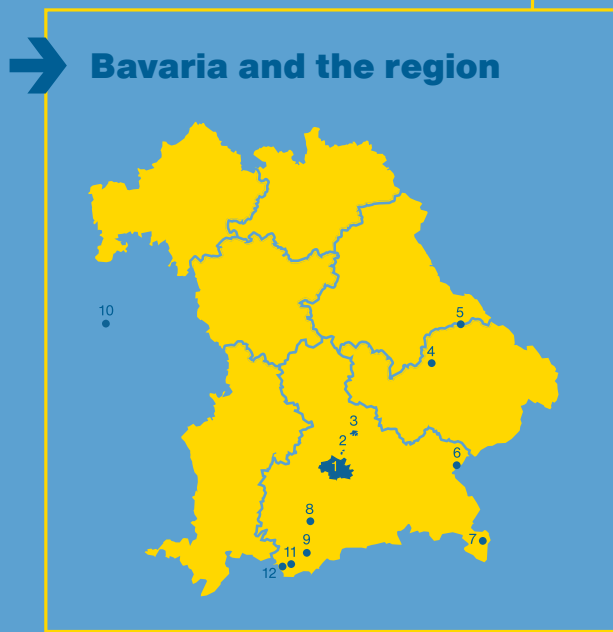
www.tum.de/en/global/international-locations

Globally Connected

Our worldwide network of research sites and locations



In our TUM.Africa Initiative, we are forging long-term partnerships in the key areas of teaching, research and entrepreneurship on the African continent.



- Bavaria and the region**
- 1 TUM Campus Munich
 - 2 TUM Campus Garching
 - 3 TUM Campus Freising-Weihenstephan
 - 4 TUM Campus Straubing for Biotechnology and Sustainability
 - 5 Geodetic Observatory, Wettzell
 - 6 Science & Study Center, Raitenhaslach
 - 7 Student Research Center, Berchtesgadener Land
 - 8 Limnological Research Station, Iffeldorf
 - 9 Hydraulic Engineering and Water Economy Research Institute, Obernach (Oskar-von-Miller Institute)
 - 10 TUM Campus Heilbronn
 - 11 Geriatrics Research Center, Garmisch-Partenkirchen
 - 12 Environmental Research Station Schneefernerhaus

48° 8' N
11° 35' O

Munich



Locations

Globally networked, rooted in Bavaria



TUMLab at Deutsches Museum



Olympic Park with Sports Center (ZHS)



Munich

For more than 150 years, the beating heart of TUM has been in Munich city center, with the Klinikum rechts der Isar and the new sports campus.



Freising

TUM's extensive and modern bio-science and life science activities are at home in the 1,200-year-old cathedral town of Freising.



2,656 m

altitude

Schneefernerhaus

TUM is a member of the consortium that controls the Environmental Research Station Schneefernerhaus. Located on the slopes of the Zugspitze, this environmental research station opened in 1998 and has since contributed to projects including the World Meteorological Organization's Global Atmosphere Watch program.

● Heilbronn



Heilbronn

Teaching and research at the interface of management, informatics and technology. TUM trains budding managers in one of Germany's most innovative regions.



**Klinikum
rechts der Isar**

Garching

TUM's largest location is the home of the university's natural and engineering sciences activities is among the most modern and best-connected research and education centers in Europe.



Straubing

Sustainability spanning across disciplines, from natural sciences and engineering to bioeconomy and economics. This unique location addresses the topic like no other in Germany.



GALILEO TUM – the new heart of the campus

Catch a film at the cinema, go to a concert, enjoy some Asian, Italian or hearty Bavarian cuisine, grab a quick coffee, give your muscles a workout, book your next holiday, or simply stock up on a few necessities of daily life – you can do all this and more at GALILEO. This multi-functional building is a congress center, business center, meditation space, leisure area, gym and shopping mall all in one; it also includes a hotel and guesthouse, and provides space for new quality of life on campus.

© Source of text and data: www.galileo-tum.de

- 36,000 m²** of above-ground space at GALILEO
- 1,300 seats** in the Audimax for lectures and events
- 540 spaces** in the parking garage

10,055 km

MUC → SIN



TUM Asia Singapore

To this day, TUM Asia remains the only international location of a German university, conveying key competences in natural sciences, engineering and management to German standards. TUM Create conducts on-site research into the potential of networked mobility in megacities.

1,262 m

altitude



Berchtesgaden

TUM's Friedrich N. Schwarz Research Station opened in July 2019. It is dedicated to topics including environmental and ecosystem research and explores new paths in the field of natural sciences education. The new teaching and research station is expanding its topic spectrum, in terms both of education and research, and also serves as a meeting place and a creative retreat for all TUM institutions.



Raitenhaslach

A space for people from the worlds of science, business and politics to meet, exchange ideas and inspire one another. The TUM Science & Study Center in Raitenhaslach carries the spirit of the Cistercian monks into the modern day.



Milestones

The history of TUM



E² 2014

Researchers map the human proteome.



2008

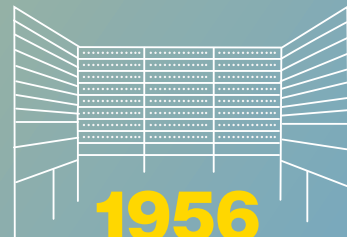
A patient receives the first-ever double arm transplant.

E¹



1928

Hans Fischer synthesizes blood's red colorant, hemin, in a test tube (Nobel Prize, 1930).



1956

The Programmgesteuerte Elektronische Rechenanlage München (PERM) is developed. It is the fastest computer in the world at the time.



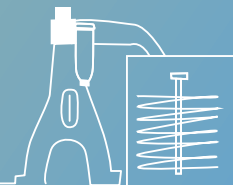
1893

Graduate Rudolf Diesel develops the engine that will come to bear his name, based on an idea he had as a student.



1868

King Ludwig II of Bavaria founded the Polytechnische Schule München as a catalyst of industrialization.



1875

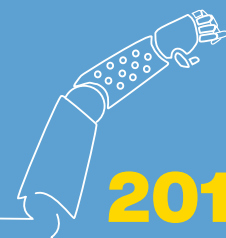
Carl von Linde constructs the first functioning refrigeration machine.



2018

The source of an extragalactic neutrino is identified for the first time.

E³

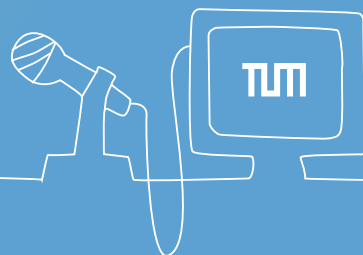


2019

Artificial skin with sensory abilities is developed for human-sized autonomous robots.

2000

The world's first minimally invasive heart valve operation is performed.



1997

A groundbreaking machine learning method – long short-term memory (LSTM) – is developed. Today, it serves as the basis of technologies such as speech recognition.



1985

Robert Huber unlocks the secrets of photosynthesis (Nobel Prize, 1988).

E³

3x Excellence Competition Winner

In 2019, we secured the title of “University of Excellence” for the third time in succession. In doing so, TUM became the only technical university to place among the winners in every round of the federal and state-level excellence competition since its inception in 2006. The prize money of €86.6 million for the period from 2019 to 2026 is enabling us to implement the TUM Agenda 2030.

Rankings

- 1** German Startup Monitor
- 6** Global University Employability Ranking (Times Higher Education)
- 41** Times Higher Education World University Ranking
- 50** QS World University Ranking
 - 25** In engineering
 - 28** In natural sciences
- 54** Academic Ranking of World Universities (Shanghai Ranking)

All about TUM

Our history, our people, facts and figures:
www.tum.de/en/about-tum/our-university

Most recent rankings: Fall 2020
 © Technical University of Munich

Selected TUM research projects

WHAT DRIVES US



S

1

Understanding the essential foundations of our existence

Where do we come from? How was the world formed? What are living things made from? We use state-of-the-art equipment and scientific methods to respond to these questions, researching the development of the universe and the structure of materials. We also conduct research into the basic mechanisms of life – from the Big Bang to the formation of the first molecules and cells through to the emergence of organoids and entire organisms.

Turn to page 46 for research into astrophysical neutrinos and page 50 for biomolecular research

3

Shaping a sustainable living environment

Taken together, the environment, the climate, energy, nutrition and resources form a complex of topics that represents one of the greatest challenges in human history. We respond to these issues and topics in our research, teaching and entrepreneurial activities through a trans-disciplinary approach incorporating natural sciences, life sciences, engineering, the humanities, social sciences, economics and medicine. We are also developing innovative strategies and technologies to protect the air, water and soil, securing natural ecosystems for future generations. At the same time, we are making decisive contributions to shaping the future of our energy supplies as well as to intelligent mobility systems. We are developing strategies and new approaches to sustainable agricultural and food production and researching potential methods of countering the impacts of climate change and species loss.

Turn to page 58 for projects in the Amazon and in Bavaria, and page 62 for research into urban development

Maintaining health and targeting diseases

What methods, techniques and equipment do we use to determine medical diagnoses? How will we treat serious illnesses such as cancer, multiple sclerosis and Alzheimer's disease in future? What surgical techniques will we use? In order to respond to these questions, we are linking medicine with natural sciences, life sciences and engineering. We are developing new technologies to sharpen our insight into the human body and researching new approaches to personalized diagnoses and treatments. We incorporate the latest scientific findings into our teaching and training for medical students and treatment for patients, thereby directly improving our offerings.

Turn to page 52 for three research projects in this field hosted by two research institutes

2

Creating new materials and advanced manufacturing technologies

New materials are the foundation of technical progress. For instance, new materials make it possible to create long-life batteries for electric cars as well as high-yield solar cells, ultra-fast computers and ultra-sensitive sensors. In numerous research partnerships in the fields of natural sciences and engineering, we research the fundamental principles for developing new materials – such as quantum effects and catalytic processes. We are developing technologies to produce innovative materials for the next generation of industrial processes and designing digital technologies for additive manufacturing, thereby enabling us to produce optimized components based on 3D designs in the core sectors of automotive manufacturing, aerospace, construction, medical engineering, and healthcare technologies, as well as chemistry and catalysis.

Turn to page 66 for research into liquid crystals and page 70 for 3D printing

Pioneering the digital transformation for a secure future

In the future, machines and robots will do far more than simply take routine tasks off our hands – especially when they have the capacity to learn. At the same time, they need to be safe, usable and controllable. We are therefore developing intelligent, self-learning machines that can assist us effectively while aligning with our ethical, social and legal frameworks.

To page 72 for robotics research and page 76 for digital medicine

Responsible research and innovation in the service of society

We are shaping technological progress for the benefit of humanity and society. For this reason, and in the interests of human-centered engineering, we are combining our traditional strengths in the natural and technological sciences with the humanities and social sciences. Whether it is robots to provide nursing care, autonomous vehicles or blockchain technologies, our researchers are developing innovations at the interface of technology, economics, politics and society. We also directly incorporate the latest findings from our research in our course curriculums.

Turn to page 78 for research into ethics in the context of artificial intelligence

6

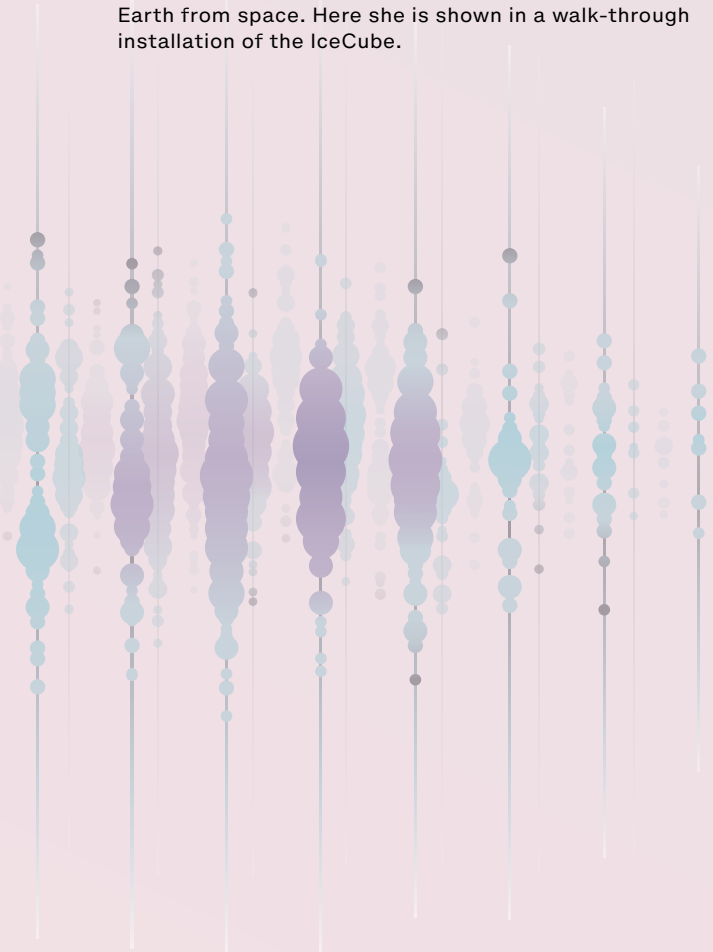
5

UNDERSTANDING THE ESSENTIAL FOUNDATIONS OF OUR EXISTENCE

Infinite Wonder

Studying mesmerizing astrophysical
neutrinos from space

Prof. Elisa Resconi, pictured here at the immersive IceCube installation, studies neutrinos that reach the Earth from space. Here she is shown in a walk-through installation of the IceCube.



→ IceCube Neutrino Observatory

IceCube is the world's largest neutrino detector. Situated at the South Pole, it is embedded in the ice mass of the Antarctic, reaching a depth of 2,500 meters. In total, the observatory occupies a cubic kilometer of ice.

»Searching for the origin of high-energy neutrinos is like sifting through circumstantial evidence in a criminal case.«

PROF. ELISA RESCONI

Our physicists at the South Pole are searching for astrophysical neutrinos from space with the aim of uncovering secrets about their location and formation.

How long will it take? A year? Five years? Fifty years? “We made an initial breakthrough after two years,” says Elisa Resconi, a professor in the Department of Physics at TUM. “We were ecstatic.” What set Elisa Resconi’s heart racing was the data she saw on her screen in Munich – data showing that an astrophysical neutrino had been detected. Neutrinos contain extremely high levels of energy and often travel for millions of years before reaching Earth.

The challenge in her research is not that these neutrinos only appear rarely. Quite the opposite: 100 billion neutrinos pass through our bodies every second. No, the challenge lies in the fact that neutrinos are unbelievably difficult to detect, as they pass through objects with ease and seldom interact with matter. This is why they can race through space – and through the Earth. However, this property also makes them extremely difficult to detect.

An ice-cold paradise

This astrophysical neutrino was detected by the →**IceCube Neutrino Observatory** – the most unusual telescope on the planet. Embedded deep in the Antarctic ice at the geographic South Pole, it comprises more than 5,000 ultra-sensitive light sensors that hang from mighty cables along with a network of sophisticated electronics. As inhospitable as this icy environment might be, it is a true paradise for researchers, enabling them to uncover the secrets of neutrinos. A team of around 40 people work at the laboratory itself, though a total of over 300 scientists from twelve countries use the IceCube data in their research.

Two years after commissioning IceCube, they all breathed a sigh of relief. “We were thrilled and relieved because we weren’t sure whether IceCube would actually be able to detect neutrinos,” recalls Prof. Resconi.

Easier said than detected

IceCube’s sensors do not “see” neutrinos directly. Instead, they collect light signals that flash when neutrinos collide with the atom nuclei in the Antarctic ice. This creates charged particles that move faster through the ice than a beam of light, lighting up ice molecules along their trajectory. Researchers can thereby calculate the direction from which the neutrinos originated and how much energy they contain. This in turn provides indications as to which region of space they come from and how they were formed.

All this is utterly painstaking work. “Searching for the origin of high-energy neutrinos is like sifting through circumstantial evidence in a criminal case,” admits Elisa Resconi. “We need an awful lot of patience and a lot of neutrinos, which we then have to measure and analyze precisely.”

A first source

The next milestone came in 2017, when researchers were able to attribute a neutrino to a known astronomical object for the first time. By analyzing the neutrino’s trajectory, they were also to determine the exact region of space in which it originated. This region was also home to a blazar. Blazars are active galactic nuclei, black holes, which devour matter and produce jets of high-energy particles, X-rays and gamma rays directed towards Earth. When IceCube detected the neutrino, increased radiation intensity was detected from the blazar. Based on these clues, the researchers concluded that the neutrino must have come from the blazar. “It had long been suspected that blazars were a source of high-energy neutrinos, but nobody had been able to prove it,” says Resconi.

Ice and water

Blazars are one of the sources of high-energy neutrinos, but there must also be others. In order to better understand where high-energy neutrinos come from, researchers need more telescopes. These telescopes do not necessarily need to be embedded in ice like IceCube: water can also be used to detect neutrinos.

Elisa Resconi and her team are therefore examining a new location in the Pacific Ocean, where colleagues from Ocean Networks Canada have already built a gigantic deep-sea observatory and research laboratory called NEPTUNE. More than 800 kilometers of fiberglass cables connect the underwater laboratory to land. The clean, transparent water of the Pacific is just as suitable for neutrino detection as the ice at the South Pole, as initial examinations by Elisa Resconi's team have demonstrated. Resconi is now seeking to erect a new telescope in the Pacific – and thereby monitor regions of space not visible from the South Pole. In doing so, the researcher and her team hope to gain a better understanding of thus far unknown properties of neutrinos.

Like being a child again

So, when will the next milestone come? In a year? In five years? In fifty years? "The outside world only sees the major discoveries," says Prof. Resconi. "But we take a small step forward every day, which is an elementary step towards major breakthroughs." Mustering the necessary patience requires no small amount of self-motivation – and a hint of madness, too, as Prof. Resconi admits. She describes this madness as akin to a child's joy of discovery – a joy it is important to retain. After all, who can help but wonder at the vastness of the cosmos?



IceCube comprises more than 5,000 light sensors just like this one. These sensors are so sensitive that they react to just a single photon.

»We need an awful lot of patience and neutrinos to produce precise measurements and analyses.«

PROF. ELISA RESCONI

UNDERSTANDING THE ESSENTIAL FOUNDATIONS OF OUR EXISTENCE

The Power of Molecules

What we can learn from chemistry



Prof. Michael Sattler in conversation with Dr. Alisha (Jonesy) Jones in the 700m² measurement hall at the BNMRZ. This hall houses the center's NMR spectrometers – the most important instruments at the researchers' disposal.



Bavarian NMR Center (BNMRZ)

For the researchers at the BNMRZ on the Garching Research Campus, detecting biological macromolecules is just one of their tasks. They also develop new, experimental methods, not only for nuclear magnetic resonance but also for magnetic resonance imaging and quantum computing.

www.bnmrz.org

»We have effectively found the key that will allow us to lock out certain diseases.«

PROF. MICHAEL SATTLER

Researchers at the Bavarian NMR Center (BNMRZ) investigate the structure and internal mobility of biomolecules in order to understand their influence on diseases.

The first challenge? To find the right key for a lock, you need to know its structure. The second challenge? What to do when the lock keeps changing...

This is perhaps the clearest way to imagine the challenges facing researchers at the **BNMRZ**. They are entirely focused on biomolecules; more precisely, they are interested in their structure, their internal mobility (dynamics) and how they interact with one another. Researchers hope to gain a better understanding of how biomolecules work in our cells, which will make it possible to develop new active substances and medications.

Strong attraction

Their most important technique at their disposal is nuclear magnetic resonance (NMR) spectroscopy. Most of the center's 12 NMR spectrometers, which measure up to 3.5 meters tall, are situated in the 700m² measurement hall at the BNMRZ. Each of these devices contains a very strong magnetic field. People with pacemakers are therefore not allowed in the vicinity. When researchers expose molecules to this magnetic field, their nuclei react in very specific

ways. It is this behavior that interests the researchers, as it provides detailed insights into a molecule's structure and internal dynamics. This information also makes it possible to understand the molecular basis of diseases like African sleeping sickness, a parasitic infection transmitted by tsetse flies. Information on the structure of the parasites makes it possible to develop new medications to treat the disease.

In simple terms, researchers have discovered a molecule that blocks a vital protein for the parasites. "We have effectively found the key that will allow us to lock out certain diseases," explains Prof. Michael Sattler, Director of the BNMRZ. He and his team are now working to develop a new medication based on this active substance.

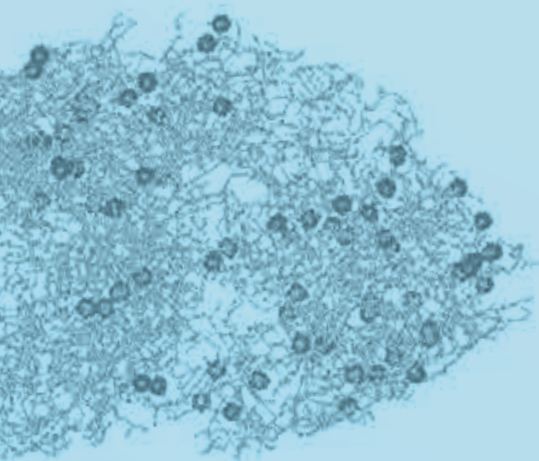
The third challenge? In the case of some diseases, such as Alzheimer's, there is simply no keyhole to find. Instead, the disease is caused by improperly folded proteins that form into clumps within or between cells. However, these agglomerations can also be closely examined using NMR spectrometry.

In the near future, researchers at the BNMRZ hope to go further than ever before thanks to one of the world's strongest NMR spectrometers, which features a magnetic field of almost 30 tesla. This will allow them to analyze more complex proteins and their interactions; ultimately, the stronger the magnetic field, the higher the data quality.

MAINTAINING HEALTH AND TARGETING DISEASES

Building a Healthy Future

Modern means of fighting diseases: New technologies are sharpening our insight into the human body



The brain of the fruit fly *Drosophila* contains around 100,000 nerve cells – around one millionth of the number of nerve cells in the human brain.

Eating disorders

The notion that a fruit fly can help us understand human behavior sounds somewhat outlandish at first. Not so, argues Prof. Ilona Grunwald Kadow. “Although a fruit fly’s neural network is nowhere near as complex as that of the human brain, it is made up of the same patterns,” explains the researcher. Understanding fruit flies can help us to understand people better. Take addictive behavior, for example: humans and animals should both know when to stop. This is a decision taken in areas of the brain responsible for cognitive function, but the olfactory receptors in the nose alter our perception. An altered perception can result in the brain’s stop signals not being sent or processed. Such insights can be important, for example, for treating eating disorders and addictions. “Once we understand the basis of such behavior, we can intervene in a targeted manner to prevent disorders before they occur,” says Prof. Grunwald Kadow.



The neural networks involved in chemosensory processing are Ilona Grunwald Kadow’s field of interest.



Prof. Stephan Sieber's goal is to develop new medications against multiresistant bacteria.

Multiresistant germs

Multiresistant germs are responsible for several thousand deaths in Germany each year. "In the **→aBACTER research project**, we have now successfully developed an antibiotic effective against these germs," as a delighted Prof. Stephan Sieber enthuses. The active substance it contains attacks different cell processes within the germs; this makes it less likely that bacteria will become resistant, as they would have to simultaneously develop resistances in all the various cell processes under attack.



aBACTER

Prof. Stephan Sieber's project team has discovered a new antibiotic that is highly effective against multiresistant gram-positive strains of bacteria and does not lead to the development of any form of resistance.

www.department.ch.tum.de/oc2/abacter

Basic research into cancer

Almost half of all Germans will develop cancer during their lifetime. A detailed understanding of the proteins involved may hold the key to developing more efficient treatment methods. With this in mind, an interdisciplinary team of biochemists and bioinformaticists has come together at the TUM Chair of Proteomics and Bioanalytics. These researchers have, for the first time, successfully mapped almost all of the roughly 20,000 proteins in the human body and made them available in the ProteomicsDB database. "ProteomicsDB allows us to make vast amounts of data on human proteins and cancer medications available to the entire scientific community. It is a significant milestone towards better understanding the mechanisms of cancers and different medications' mechanisms of action, thereby fathoming out more targeted treatment methods," enthuses Prof. Bernhard Küster.



Prof. Bernhard Küster and his team are focused on analyzing proteomes.

Patient care

Quickly translating the results of medical research into practice in patient care is the mission of TranslaTUM – one of the most advanced cancer research institutes in Germany. Situated at the heart of the TUM campus at the Klinikum rechts der Isar, the institute allows researchers, engineers and doctors to collaborate on preclinical research under a single roof. Working together, they validate their results in the fields of patient diagnostics and treatment. Their research includes exploring how the immune system detects and fights cancer as well as the genetic changes cancer causes. Work is also underway to develop a new medical imaging and analysis technique to detect tumors more effectively than ever before.

A home for science

“The interdisciplinary concept and modern infrastructure create optimal conditions for scientific and medical progress,” emphasizes Prof. Jürgen Ruland. The institute provides a home for the work of engineers, biologists, medical specialists and numerous other experts.



Prof. Jürgen Ruland in discussion: Simple structures, interdisciplinarity and modern infrastructure are all hallmarks of TranslaTUM.

Neurological diseases

Whether Alzheimer's disease, multiple sclerosis or strokes, the underlying mechanisms and causes of neurological diseases often share commonalities. "Diseases don't limit their scope, so research shouldn't limit itself either," says Prof. Thomas Misgeld. He also argues that researchers should collaborate closely across disciplines and also work hand-in-hand with doctors. At the SyNergy Cluster of Excellence – Munich Cluster for Systems Neurology, or SyNergy for short, they do exactly that. SyNergy has overcome another boundary, as it enables researchers from TUM to work closely together with researchers from Ludwig-Maximilians-Universität München (LMU) and other institutes.

No limits

"We have joined forces as we strive to better understand neurological diseases and quickly implement the results of our research in practice for the benefit of patients," says Prof. Thomas Misgeld, neatly summarizing the cluster's aims.



From the lab to hospitals: Collaboration between researchers and doctors is particularly important to Prof. Thomas Misgeld.

SHAPING A SUSTAINABLE LIVING ENVIRONMENT

The Fragile Balance

How is climate change impacting
on our ecosystems?



In two research projects, one in Bavaria and one in Brazil, we investigate the impacts of climate change on our planet.

“Asphalt road for 40 kilometers, then a muddy road for another 30 kilometers into the rainforest,” says Prof. Anja Rammig, describing her commute to work. Her destination? A field station in a nature reserve some 70 kilometers from Manaus in the Brazilian northwest, where the forest is still untouched by humans. “Almost, anyway,” says Anja Rammig. “Nowadays, every ecosystem is influenced by climate change. Even almost untouched parts of the Amazon.”

In the →**AmazonFACE** project, Anja Rammig works alongside other researchers to investigate the influence that the rising concentration of carbon dioxide will have on the ecosystem in future and how this could affect the entire planet. As part of this research, the field station holds trees and plants in chambers standing two to three meters tall to simulate the likely concentration of carbon dioxide in the atmosphere in 20 years’ time. Carbon dioxide is a fertilizer for trees. For humans, however, the increasing concentration of carbon dioxide in our atmosphere will be a major challenge in future. “The reduction in forested land will lead to less carbon dioxide being captured; it will then stay in the atmosphere and intensify the greenhouse effect,” explains Anja Rammig. In future, experimental towers arranged in a circle will simulate the elevated concentration of carbon dioxide for an entire ecosystem. Nevertheless, the

smaller chambers have already yielded answers to various questions. “How much carbon do trees store? How much do they use to form leaves? What happens when trees take in more and more carbon? Does their biomass change – such as the ratio of carbon to phosphorous – or do trees take carbon in from above before expelling it again through their roots?” says Anja Rammig, outlining the questions that occupy her mind.

From the Amazon to Bavaria

Anja Rammig’s second workplace could hardly be more different to the Amazon. Surrounded by fields and coniferous forests in Weihenstephan, Bavaria, the modern campus of the TUM School of Life Sciences offers the perfect conditions for

→ AmazonFACE

This international project researches the impacts of climate change in the rainforest. FACE stands for “free air CO₂ enrichment”, the term given to a technical experimental set-up that generates a defined concentration of carbon dioxide outdoors.

www.lsa.wzw.tum.de/en

»The increasing concentration of carbon dioxide in our atmosphere will be a major challenge for humanity.«

PROF. ANJA RAMMIG

research. Yet as different as Rammig's workplaces and the ecosystems under investigation might be, the questions on her mind are the same: How do climate change and the droughts it entails affect trees? Whether in the Amazon or Bavaria, the same effects impact on tree growth, vegetation and productivity.

vegetation globally that can also be adapted to regional characteristics. Ultimately, evergreen tropical plants react in a different way to a beech or spruce. In future, this model will make it easier to identify which species of tree are most capable of adapting to climate change and decide how best to manage forests. "This is about the very foundation of our existence," emphasizes Anja Rammig.

Whether palm trees or beech, the basis of human existence is under threat

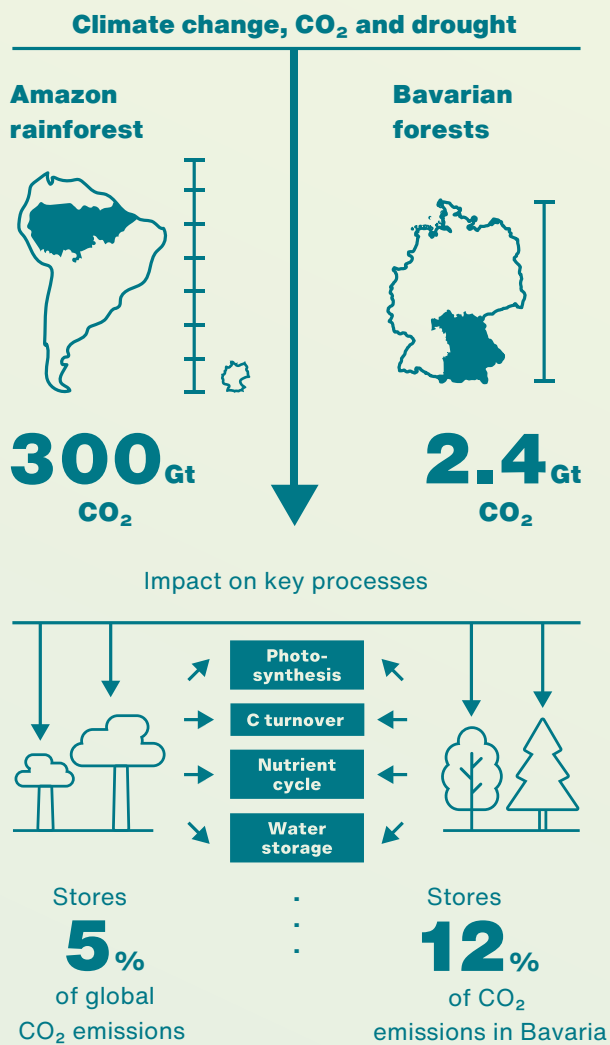
In Weihenstephan, Anja Rammig heads up the **→View into the Future (BLIZ)** project, in which researchers examine large-scale interactions: How does society impact on ecosystems? And how does climate change impact on society? The goal is to develop a model capable of simulating

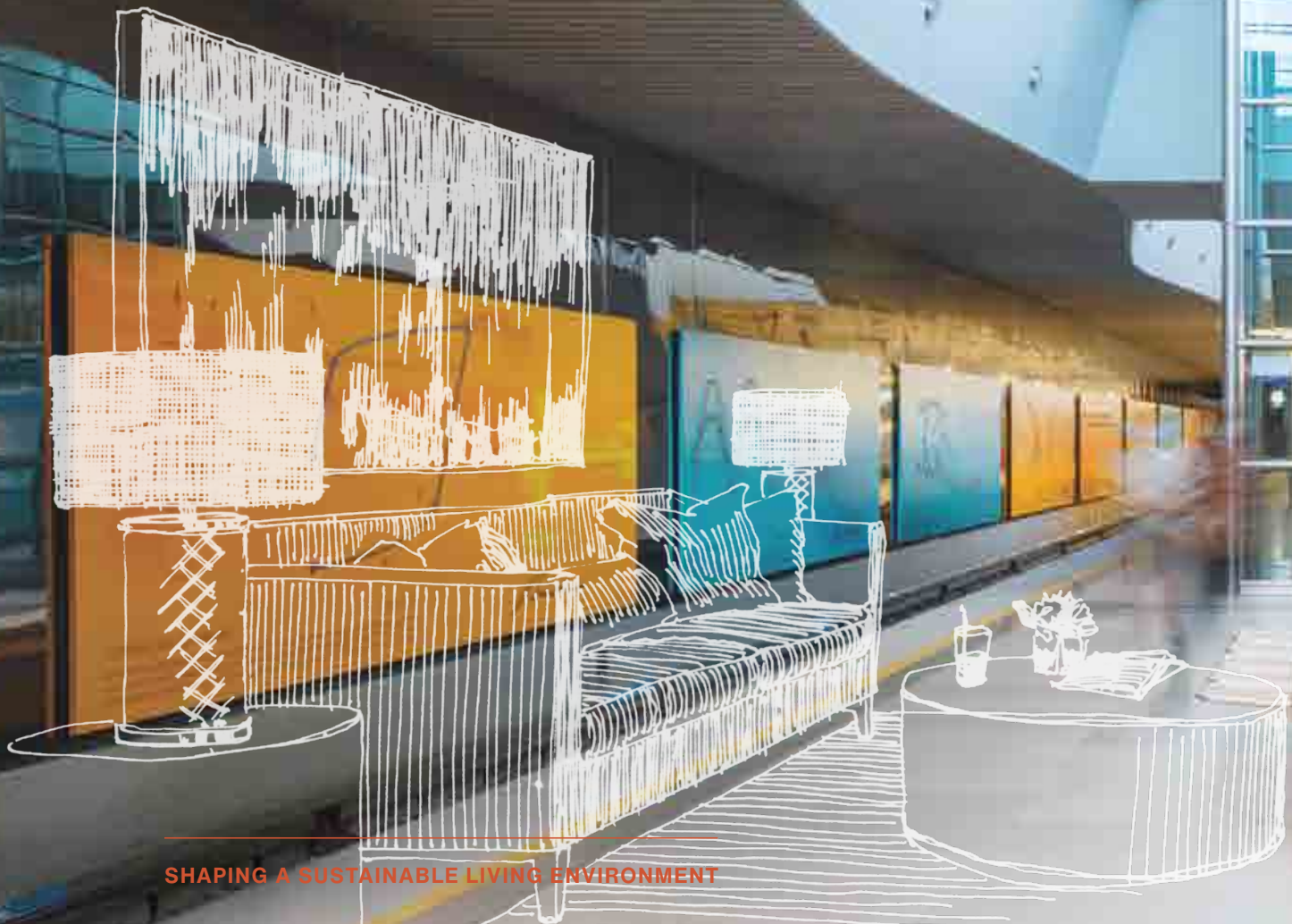


View into the Future (BLIZ)

This project researches the interrelations between society, land use, ecosystem services and biodiversity in Bavaria up to the year 2100. It aims to derive specific instructions to promote sustainable ecosystem management.

www.bayklif-bliz.de





SHAPING A SUSTAINABLE LIVING ENVIRONMENT

The City of the Future

How can we make our built environment
attractive for people again?





Residence, Work, Mobility (WAM)

An interdisciplinary research team. A survey with 7,300 respondents. The world's first interactive map depicting the mechanisms at work when people search for an apartment. Answers to how major cities can rise to the challenges of the future. These are the results of the Residence, Work, Mobility (WAM) project.

Architects are researching and teaching new methods to modernize cities while conserving resources.

Flying cars, kilometer-high buildings, chrome sidewalks – in truth, Hollywood directors' visions of cities of the future have very little in common with modern-day cities – and would leave little room for parks and green oases for city residents. The vision put forward by Prof. Alain Thierstein is considerably more practicable and livable. "A polycentric city featuring a host of different focal points, shortened transport routes and a new division of street space," says Alain Thierstein, who has researched and taught at TUM for the last 15 years. "We need to free ourselves from the diktat of the car lobby. People want to walk, travel by bike and meet with others. We need a transformation towards a human-centered city." So, why is there such a gulf between the two

visions? Well, Alain Thierstein's vision is based on decades of research and input from an entire team of scientists from different disciplines. "We work, discuss and visualize together, proceeding with an interactive approach," says Thierstein. As a result, the Chair of Urban Development is home to architects, urban developers and economic geographers.

How would I like to live?

This interaction also laid the foundations for the **→Residence, Work, Mobility (WAM)** project, which Thierstein initiated in 2017 alongside Prof. Gebhard Wulforth. A ten-strong team drawn from the fields of architecture, economics, geography, cartography and geographic information systems investigated which factors mattered most for people looking for places to live and work in Munich. The focus lay on identifying the decisive criteria in determining the best locations and how these criteria are related.

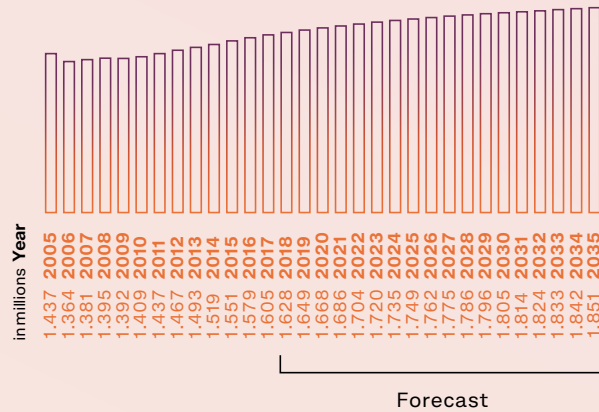
The study's participants, of which there were over 7,000, used maps to show how they made their decisions. They showed where they had lived previously, where they live now, where they work, and the areas in which they had looked for a new home. At the end of the study, the team were able to demonstrate how these weighing-up decisions actually work. This was a world first. The team then identified five area types and issued recommendations as to how the Munich metropolitan region should prepare for the future. These included creating versatile spaces, growing the city vertically, and structuring people's lives to be as efficient as possible.

»At the Chair of Urban Development, interdisciplinary is our core principle.«

PROF. ALAIN THIERSTEIN

»We have an obligation to use resources more carefully.«

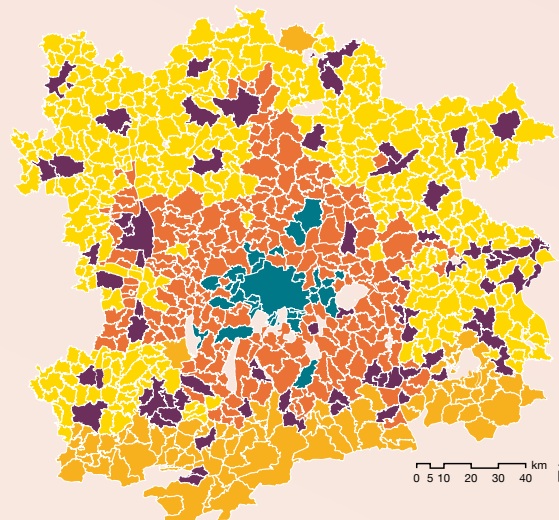
PROF. ALAIN THIERSTEIN



Population growth and forecast, 2005 to 2035.
© Source: see imprint

Promoting public transport over cars

Transport planning is particularly important. Wherever possible we should prevent people from wasting valuable time commuting to work. Intelligently planning transport routes and expanding local public transport services are the most important measures in this context. The solution? Establishing tangential transport connections and public transport routes with ring structures that spread out to create a sort of transport net. This creates new centers around transport interchanges, which then become the focus of residents' lives. "This reduces the burdens on streets and allows space to be allocated to different, more people-friendly uses," explains Prof. Thierstein.



- urban, central
- urban, decentralized
- urban commuter belt
- residential areas with tourist appeal
- peripheral areas

Spatial-functional cluster structure of the Munich metropolitan region. © Source: see imprint



CREATING NEW MATERIALS AND ADVANCED MANUFACTURING TECHNOLOGIES

The Language of Crystals

When experimental physicists become gold miners

»We're discovering material properties we never even knew existed. We're permanently astounded.«

PROF. CHRISTIAN PFLEIDERER

At the Chair of Experimental Physics on the Topology of Correlated Systems, we search for electronic properties in materials that could completely transform our day-to-day lives.

Examining materials with the aim of discovering something that could change the world requires patience. The team of around 20 researchers at the Chair of Experimental Physics on the Topology of Correlated Systems know that very well. Under the leadership of Prof. Christian Pfleiderer, their research searches for the secrets of crystalline solids under extreme conditions. But if there's one other thing they know, it's that patience yields rewards. A look back at the century before last is proof of this.

In 1888, Austrian chemist Friedrich Reinitzer discovered so-called liquid crystals. At the time, scientists were fascinated by the vibrant patterns found in certain organic liquids. However, despite being able to observe these patterns, they

Prof. Christian Pfleiderer's goal is to unlock the secrets of crystals and metals.

were not able to actually do anything with them. It would take some 70 years for this to change, when scientists learned how to control these patterns electrically for optical applications. Today, liquid crystals can be found everywhere, from television sets to thermometers to laptop screens. The man who discovered liquid crystals was not around to all see this for himself.

"The discovery of vibrant patterns in liquid crystals is a wonderful example of our work," says Prof. Pfleiderer. "We look for certain textures in the electronic properties of materials, which are dominated by quantum entanglement. Of course, exactly what society can make of this will only become clear in future." In the past, developmental stages have lasted decades. Even if researchers find shortcuts on the route to the technical application of their findings, this work will still demand stamina and patience.

Discoveries lead to inventions

But what exactly might the liquid crystals of tomorrow be? And what would we use them for? We actually already have a fairly good idea. The quantum materials that Christian Pfleiderer and his colleagues are researching will likely make it possible to produce new types of sensors, energy-efficient data-storage systems, and perhaps even new components for quantum computers, which could in turn have a massive impact on the course of information science and other key future technologies.

"We're discovering material properties we never even knew existed," says Prof. Pfleiderer. "That's what makes our work so exciting. We determine characteristics under conditions where we anticipate the results to contradict what the textbooks say. When we actually discover anomalies, we're overcome with the delight that gold miners feel and begin to think about what purely practical applications we might find for these new material properties."

Hunting for the finest crystal

On the TUM campus in Garching, Christian Pfleiderer and his team work in laboratories with highly complex equipment in which the crystals are initially grown. "We procure different elements, such as iron, manganese and silicone, and smelt them down under the purest conditions," explains Pfleiderer. "We use them to create special bars we can use to grow so-called monocrystals."

These crystals might seem like just the starting point in this research. However, their significance should not be underestimated. "New properties only appear frequently in the very purest crystals," says Pfleiderer. "Growing them

takes years of work. When you find the right parameters, it's like Easter, Christmas and your birthday all at once."

In the next stage, after the crystals have been grown, their properties are measured under extreme conditions – such as at temperatures as low as 0.01 kelvin, effectively absolute zero, under magnetic fields and atmospheric pressures a hundred thousand times the normal levels found on Earth. What happens to materials' resistance, magnetization and thermal capacity under such conditions? These measurements provide insights that are followed by extensive investigations with neutron radiation and X-radiation, such as at FRM II and many other major research institutes.

Although it may not always be obvious to the general public, Christian Pfleiderer and his colleagues are constantly generating new insights. "In truth, we're permanently astounded. Once you realize you have detected an anomaly in a measurand that you didn't quite expect, it gives us all a tingling sensation."

Research for the everyday of the future

One of the long-term topics at the Chair of Experimental Physics is research to discover ordering phenomena caused by quantum correlations. Pfleiderer and his colleagues enjoyed success in this regard in 2009, with the identification of a lattice of vortex-like structures in magnetic materials, so-called skyrmions, which provided proof of completely conventional ordering and thus magnetic pattern formation that had gone overlooked for decades. Their topology follows a model conceived by British physicist Tony Skyrme for the neutrons in nuclei. Just as was the case for the liquid crystals used today in LCD displays, the theoretical foundations had been laid some seven decades previous.

"It just takes time," says Prof. Pfleiderer. "True discoveries can't be rushed – at most, you can give them a nudge." However long it might have taken, Christian Pfleiderer's work has inspired many of his colleagues. The paper he published in 2009 led to numerous other research papers in which skyrmions were shown to exist in countless other material classes. And, who knows, maybe ordinary citizens will one day use the results of this research, perhaps in ultra-sensitive sensors or in their laptops or smartphones.

Prof. Christian Pfleiderer grows and researches liquid crystals. He is always in search of new material properties that have not yet been discovered.



»Once you realize you have detected an anomaly in a measurand that you didn't quite expect, it gives us all a tingling sensation.«

PROF. CHRISTIAN PFLEIDERER



Even bones and complex hip joints can now be produced using 3D printing.



→ **TUM Design Institute**

The TUM Design Institute serves to combine systematic thinking, engineering expertise, knowledge of the natural sciences and technological proficiency with entrepreneurial culture, Design Thinking methods and design tradition with the aim of adding value to innovative product and process design methods.

CREATING NEW MATERIALS AND ADVANCED MANUFACTURING TECHNOLOGIES

Printing the Future in 3D

A revolution in manufacturing technology

»New technological aspects and start-ups come onto the market every day; we are constantly surprised by the innovative approaches involved.«

PROF. KATRIN WUDY

Two new Chairs at TUM are researching the manifold potential of 3D printing. One is primarily focusing on materials, while the other is concerned with processing them. Their research success is due in part to this synergy.

The offices of the Chair of Materials Engineering of Additive Manufacturing are filled to the brim with copious examples of 3D printing, from hip joints to titanium turbine blades, individualized structures and much more besides. All these objects were once created using one of the 3D printers that Prof. Peter Mayr and his team work with, day in and day out.

Since the fall of 2019, the team at the newly founded Chair have been working to determine exactly how 3D printers can become more than just a trendy gimmick that has attracted considerable attention in recent years – including beyond the scientific sphere. In fact, this technology is now being used in more and more areas of industry. “It’s fascinating that, within just a few hours, 3D printing allows you to turn an idea into something you can hold, observe and examine with your own eyes,” says Mayr.

It is already possible to manufacture complex components from a single material. In the future, however, it is hoped that 3D printers will be able to construct objects from different materials in a single printing process, producing what are known as multi-material components. Only then will the technology be able to fulfill the complex requirements of industry. Mayr likes to explain this with the help of a simple example: At present, most scalpels are made from a single material and are disposed of after a single use. “But what would happen if we could manufacture the body and the cutting edge from different materials? We could make the body from a cheap, flexible material and the cutting edge from a highly durable material,” says Mayr. “A scalpel built like that would be a highly efficient tool, and also reusable at the same time.”

It’s all about how processes and materials interact

Just five minutes from Mayr’s office, in the next section of the building, is Prof. Katrin Wudy’s workspace – also part of the School of Engineering and Design on the TUM campus in Garching. The short distance between the two is thoroughly sensible. “It’s a perfect symbiosis between our two professorships,” says Wudy, who holds the professorship of Laser-based Additive Manufacturing. “My professorship is focused on new process technology approaches in the field of additive manufacturing, such as relating to laser technology. Prof. Mayr’s professorship is focused on materials and their properties.” Only when both aspects are optimized – both the process technologies and the materials – can the researchers achieve optimal results. “We find ourselves in such a dynamic research environment,” explains Wudy, “that new technological aspects and start-ups come onto the market every day; we are constantly surprised by the innovative approaches involved.”

A 3D printer in Alaska should be able to print in exactly the same quality as a printer in South Africa

Despite the fact that printing components is possible today, the technology is not yet fully developed. If you stand two 3D printers side by side and instruct them to print the same part, the results will currently be quite different. This poses a major challenge for industrial quality assurance processes. Although these differences are barely discernible to the untrained eye, examining the structure and properties of objects using highly specialized technology shows up the variations. These can be caused by issues such as temperature fluctuations and varying laser performance. In design objects, these variations are usually not critical – but when it comes to airplane turbine blades, variations can have fatal consequences. The quality demands are exceedingly high. “Ultimately, the expectation is that a replacement part printed in Alaska will have the same properties as a part printed in South Africa,” says Mayr.

»If you print a replacement part in Alaska, it should have the same properties as a part printed in South Africa.«

PROF. PETER MAYR

PIONEERING THE DIGITAL TRANSFORMATION FOR A SECURE FUTURE

Who Matters More?

Why machines are assisting humans,
not replacing them

Striving for sensitivity: Prof. Sami Haddadin develops robots that support humans.



➔ Munich School of Robotics and Machine Intelligence (MSRM)

The goal of this integrative research center is to research the fundamentals of robotics, perception and artificial intelligence in order to develop innovative and sustainable technological solutions to the central challenges of our times.

www.msrm.tum.de/en

»Robots can use this knowledge constructively; this networking suddenly and massively accelerates their learning process.«

PROF. SAMI HADDADIN



Although robot hands remain someone maladroit, Prof. Sami Haddadin's research aims to make them increasingly sensitive and precise.

At the Munich School of Robotics and Machine Intelligence (MSRM), we are developing intelligent machines that can assist us in our lives.

They will be able to care for the elderly, take care of domestic chores, and send the children off to sleep with a patient bedtime story. They look like humans, hence the name "hubot": a portmanteau of "human" and "robot". So far, so helpful. In the Swedish drama series "Real Humans", however, some of the hubots develop their own thoughts and feelings, to which the human characters are receptive. An old man develops a deep friendship with his hubot carer; a lawyer defends the rights of hubots, and some people fall in love with their hubot. This is where it becomes problematic – and dramatic. When the boundaries between man and machine disappear, the question of power automatically arises: Who matters more?

In the real world, things should not get that far. "We are developing machines that will benefit humans – not replace them," says Prof. Sami Haddadin, Acting Director of the **→Munich School of Robotics and Machine Intelligence (MSRM)**, which was founded in 2018. "With this in mind, humans are always the focus of our considerations."

Supporting the sick and elderly

Nevertheless, there are some similarities between the MSRM's research and the TV series "Real Humans". For example, scientists at the MSRM are developing an intelligent two-armed robot assistant called GARMI to assist older people with everyday tasks, such as getting up, preparing food and clearing the table. In addition, doctors can connect with GARMI and thereby remotely diagnose patients, take ultrasound images, and prescribe medication. Thanks to GARMI, older people will be able to live independently within

their own four walls for longer than has been the case to date. Another MSRM project focuses on smart rehab robots, specially developed to assist heart attack patients and people who have recently undergone surgery. Equipped with sensors and machine learning algorithms, these robots can assess and analyze a patient's quality of movement, mobilize muscles and stimulate nerves. Following the instructions of a physiotherapist, robots take patients by the hand and guide them so that they learn to perform certain tasks again and regain motor control, little by little. They can also identify when a patient is capable of performing movements on their own and when they require assistance.

exceptionally complex." This level of flexibility is not easy to reproduce. Like fitting a key into a lock, it requires a very delicate approach and an aptitude for learning. As a result, Sami Haddadin constructed an entirely new mechanism based on the model of the human locomotor system. Despite this, the human hand is and remains more precise than that of a robot.

Yet Haddadin's interests in this project are far broader; he is driven by a vision in which robots can pass on what they have learned to other robot colleagues. The idea came to him when he considered all the machines around the world that perform a single, small task, without being particularly efficient overall.

»What humans are capable of is almost miraculous. The human locomotor system alone is exceptionally complex.«

PROF. SAMI HADDADIN

Research for the good of humans

Technical assistance systems like these are becoming increasingly important for elderly and sick people, particularly in times of demographic change and an aging population. This and other major social challenges are what drives the work of the MSRM and are the focus of the research agenda pursued by Sami Haddadin and his colleagues.

One discipline alone will never be able to solve and respond to these challenges. Technical development is but one instrument in a concert of questions. Will society accept robotic assistance systems? What are the legal implications? "Pure specialism simply cannot solve the immense challenges facing society, which is why our science must be interdisciplinary in nature," says Sami Haddadin. TUM is an international leader in this field – our university already has 50 professors dealing with different disciplinary competences and aspects of machine intelligence.

Precise, interconnected robots

An understanding of humans forms the basis of their actions. "What humans are capable of is almost miraculous," says Sami Haddadin. "The human locomotor system alone is

"That won't work well in the long term," he thought. Given that knowledge cannot simply be transmitted down a telecoms line, machines must be able to learn, generalize the knowledge they acquire and share this knowledge with other machines. "Not only can robots pass on this knowledge, they can use it constructively – which suddenly and massively accelerates their learning process," explains Prof. Haddadin. He envisages a global network of interconnected, learning robots.

In research and in practice, humans are the focus

How fast will robots change our society and the world of work in the age of the digital transformation? Sami Haddadin does not think it is possible to make reliable predictions. If all of today's research is integrated in our daily lives in ten years' time, he says, it will represent a major step forward. As a result, Haddadin is collaborating with colleagues, industry partners and start-ups with a view to trialing and implementing what he has developed in everyday scenarios. Just as in his research, he strives to work with people who are driven by forward-looking visions and are not limited by boundaries. "Many founders have unique skills that need to be supported and integrated on an equal footing. The same principle applies here: Humans must be at the heart of our work."

PIONEERING THE DIGITAL TRANSFORMATION FOR A SECURE FUTURE

Diagnoses at the Push of a Button

How artificial intelligence is enhancing
medical diagnosis

➔ Linking medicine with AI

Researchers in the fields of medicine, informatics and artificial intelligence work hand-in-hand to drive forward innovation in medical imaging.

Generating, analyzing and interpreting more diagnostically conclusive images than ever before – three tasks that, it is hoped, neural nets will be able to master. If successful, it would enable them to support radiographers substantially in future with highly meaningful diagnostic input.

The patient lies as still possible as she slides into the MRI scanner. As still as possible. Despite this, her heart keeps on beating and her arteries keep pulsing. All through the scan, the fetus

diagnostically conclusive images than ever before and are better able to identify tumors and lesions.

More data, higher quality, better diagnoses

And that's just the beginning. Daniel Rückert and his team aim to develop this technology so that it is able not only to produce diagnostically conclusive images, but to analyze and interpret them as well. In this context, the more data is available, the higher the data quality will be. But where exactly

»Although humans are immediately able to interpret movements for what they are, machines have to learn to do so.« PROF. DANIEL RÜCKERT

in the expectant mother's womb is moving as well. In the past, such movements presented a problem for automated techniques for analyzing tomographic images. "Although humans are immediately able to interpret movements for what they are, machines have to learn to do so," explains Prof. Daniel Rückert. He has now trained them to do just that by harnessing artificial neural networks, which can analyze unstructured data like images particularly effectively and identify patterns in them. By feeding these networks with a mass of data, Rückert "taught" them to identify movements and depict organs in three dimensions. Consequently, imaging techniques such as MRI and CT scans can now generate more

can they find this data? Data protection is a huge priority in medical contexts. "One approach is to use data that is not stored centrally but instead remains with the party who collected it," explains Prof. Rückert. This method is known as privacy-preserving machine learning.

Rückert and his team are now working to improve data quality and refine the techniques. In the future, tomography systems will be capable of issuing findings and reports at the push of a button, making the work of radiologists significantly easier. Ultimately, however, determining a diagnosis and informing the patient is set to remain a task reserved for humans for the foreseeable future.



Institute for Ethics in Artificial Intelligence (IEAI)

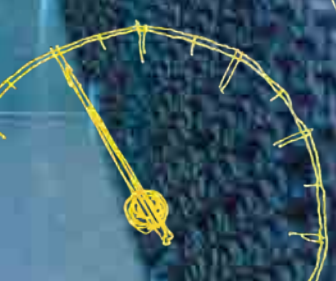
We founded the IEAI in 2019 with the aim of contributing to efforts to make AI-based technologies trustworthy and socially acceptable. To this end, the IEAI unites our scientific and technical disciplines with the humanities and social sciences. The institute's researchers explore the ethical challenges that arise at the interface of technology and human values. One of their goals is to generate global, interdisciplinary guidelines for the ethical development and implementation of AI throughout society.

ieai.mcts.tum.de

RESPONSIBLE RESEARCH AND INNOVATION IN THE SERVICE OF SOCIETY

Do Computers Have a Conscience?

Teaching artificial intelligence
to exercise moral judgment



Image, right: How ethical are our digitalized lives? Researchers at the IEAI not only want tomorrow's algorithms to be more intelligent than their current counterparts – they want algorithms to be able to make more reasonable decisions.

»Ethical discussions previously focused on the fundamentals; today, the focus is on the details.«

PROF. CHRISTOPH LÜTGE

At our newly founded Institute for Ethics in Artificial Intelligence (IEAI), we aim to make digital aspects of our lives more reliable and responsible.

Founded in 2019, the → **Institute for Ethics in Artificial Intelligence (IEAI)** is home to around 40 scientists working to teach artificial intelligence (AI) to engage in ethical thinking. “This involves more than just sitting at a desk,” says Prof. Christoph Lütge, who heads up the institute. Instead, the researchers’ efforts to convey ethics to AI involves working in laboratories, testing driving simulators, and reading up on source codes. Their aim is not only for tomorrow’s algorithms to be more intelligent than their current counterparts – they want algorithms to be able to make more reasonable decisions.

This work is becoming increasingly urgent, given the onward march of AI into every aspect of our lives. Even just a few years ago, that seemed an utterly abstract concept to

Christoph Lütge, who took up the Chair of Business Ethics in 2019. Back then, his work focused on a wider question: How can we act ethically as an enterprise? Companies and institutions followed his advice by enacting mission statements and codes of ethics. The aim of this recently founded institute is to provide far more specific answers to current ethical issues surrounding digitalization. “A few years ago, it was hardly conceivable that I would be able to combine my informatics degree with my philosophy degree,” admits Prof. Lütge. Today, however, there is a very direct link between the two fields. As a result, TUM and the Munich School of Philosophy now offer their students the opportunity to combine technology and philosophy.

Preventing the spread of fake news

How can we prevent false news stories from spreading on social media? Christoph Lütge and his colleagues are currently working on a preventive approach to this issue. They hope to develop algorithms capable of detecting fake news just as it starts to circulate – that is, before it spreads on a huge scale and can no longer be stopped. Conceivable measures include displaying warning messages, such as: “Are you sure you want to share this post?” However, even solutions like this that sound quite reasonable often entail another ethical challenge: Would displaying such warnings impinge on a person’s right to freedom of expression? Of course, there is rarely only one answer to any given problem. This makes it all the more important to align approaches – working in close collaboration with other disciplines, in this case informatics.

“Ethical” mobility

In another equally important field of research, autonomous driving, the problems are even more tangible. In this context, ethical problems are quite literally a matter of life and death. If an autonomous car’s brakes fail and it finds itself hurtling straight towards a tree, which direction should it turn? To the left, where three children are standing? Or to the right, where two pensioners are sat on a bench? “I don’t have a general answer to that,” says Prof. Lütge. “But we have to give thought to which principles we want machines to use in order to make decisions.” Ultimately, ethical issues affect many areas of our lives. The question of who would be liable if an AI makes a mistake is just one example. “Ethical discussions previously focused on the fundamentals; today, the focus is on the details,” says Lütge.

Man or machine – who decides?

So, will algorithms in future determine for themselves what is morally right and wrong? “Hardly,” says Christoph Lütge. In



»Humans rarely take objective decisions; in principle, a machine is capable of this.«

PROF. CHRISTOPH LÜTGE

the world of medicine, for example, Lütge believes the vast majority of fields will not feature fully automated decisions anytime soon. Although machines and big data can provide extremely accurate indications of how likely it is that a patient has developed breast cancer, it will still be up to doctors to make and deliver the diagnosis. “That’s why people will still

be needed in future,” emphasizes Lütge. On the other hand, “people rarely take objective decisions; in principle, however, a machine can.” In Lütge’s vision, the AI solutions of tomorrow will be able to save lives in medical contexts, drive cars more safely and make markedly fairer decisions (such as on job or loan applications) than a human ever could.



WHO



USAP





SETS



ART

The Next Gene- ration



How TUM
students are
voluntarily
serving society



»With your good quality of education here, good opportunities, I really expect that you will lead, with passion and compassion, this world to a better future.«

BAN KI-MOON

Ban Ki-moon with Silja Wöhrle and Yannik Kaiser from the TUM Speakers Series team.



Whether in competitions, university development, social projects, negotiations or on the stage, in their voluntary activities our students stand up for one another, strive to establish dialogs and develop solutions – thereby making impressive achievements, both for their university community and for wider society.

Ban Ki-moon looked into the packed Audimax at TUM. Having come to the end of his speech, he wanted to give the gathered students one last thing to take away with them. “With your good quality of education here, good opportunities, I really expect that you will lead, with passion and compassion, this world to a better future. I am full of hope in your ability and your commitment to work together for this better world.” With that, loud applause rang out around the hall.

“I felt very directly addressed by Ban Ki-moon’s closing remarks,” recalls Silja Wöhrle as she thinks back to the event in February 2020. Wöhrle is the main host of the → **TUM Speakers Series**, which organizes events like this. As the association’s co-president Yannik Kaiser recalls, “we were very tense, because we had spent weeks making preparations for our high-profile guest.” The TUM Speakers Series aims to give students exclusive insights into the work of leadership figures, their background, their ideas and their vision for the future. These interactions aim to provide the students with fresh impetus and further their own development.

That being said, it is not only the students who benefit from this exchange. The speakers also enjoy engaging with the younger generation, as Benedikt Ströbl, with whom Kaiser shares the presidency of the TUM Speakers Series, explains. “It is important to them to learn what matters to students, what students think, and what their principles are,” says Ströbl.

Improving the TUM student experience

Philipp Koch is also passionate about his voluntary work for the university. From the Board of Trustees and the Senate to his role on the Student Council, he devotes up to 40 hours each week to his various duties at TUM. “Sure, I could have just stuck to my studies and graduated as quickly as possible. But I wanted to take as much as

→ TUM Speakers Series

Tony Blair, Bill Gates, Mary Lou Jepsen and Kofi Annan have all delivered lectures at TUM. The credit for arranging these events goes to the students who make up the TUM Speakers Series and issue invitations to eminent guests on several occasions through the year. In addition to providing financial support, TUM stands ready to offer the association advice and helps it to establish contact. It now counts the Munich Security Conference, the DLD Conference and the German Council on Foreign Relations among its partners.

www.speakersseries.de

→ Student initiatives

Our students are actively involved in numerous projects, initiatives and associations. Such activities allow them to apply the knowledge acquired in their studies, often learning to think and act with an entrepreneurial mindset. Our students promote the cultural exchange on campus, coach and support young people, and campaign for human rights – establishing networks and founding friendships that span the globe.

www.tum.de/en/studies/campus-life/student-initiatives

possible with me from my time here – and give something back to TUM,” says Koch. Together with his peer Zaim Sari, Koch is a member of the TUM Board of Trustees, where the duo help to shape amendments and establish new programs of study.

His voluntary work has taught him a great deal, helping to develop him as an individual and prepare for working life. “I assume responsibility and learn the qualities that a leader needs,” says Koch. However, he believes the most important part of his work is the ability to help improve living and learning at TUM. One of his most recent successes is StudiTUM houses, which provide students with individual and group workspaces and study rooms around the clock. Koch’s attention is now focused on his next major project: setting up student dormitories on the

»We are working today for the generation after us. We want TUM to become even better for the next generation of students.«

PHILIPP KOCH

new campus in Garching – an important project for him and the other student representatives.

“We are working today for the generation after us. We want TUM to become even better for the next generation of students,” says Koch, outlining his motivation. He explains that he has benefited immensely from the dedication and commitment of his predecessors, offering as examples the MVV Semester Ticket and the abolition of student fees, which saw the → **Student Council** of TUM negotiating with Bavarian and Munich politicians.

Fast-moving developments

Students at the Department of Aerospace and Geodesy busy themselves with different questions entirely. Is it possible to travel at speeds in excess of 1,000 kilometers per hour without setting foot on an airplane? Are human beings built to withstand such speed? And what technologies might be able to make this possible?

Students are tackling these and other questions as part of their work on → **Hyperloop** – an entirely modern transport technology, of which the underlying principles have been researched at TUM for more than 20 years. The idea is that a transport capsule should travel in a concrete tube resembling a metro tunnel at speeds that would make it possible to travel from Munich Central Station to Venice in little more than 15 minutes. For the time being, this remains a utopian dream. Researchers at the Department of Aerospace and Geodesy, however, hope to make this dream a reality.

Student Council

Our Student Council represents the interests of all TUM students. Its activities range from engagement on higher education policy to arranging a variety of events and providing a wide array of services for our students. Whether by influencing changes to our programs of study or organizing major events and festivals, the Student Council actively shapes life at our university.

www.sv.tum.de



For years, Elon Musk, the CEO of electric car manufacturer Tesla and founder of space exploration company SpaceX, has invited students from around the world to travel to Los Angeles take part in the Hyperloop Pod Competition. In this competition, the young researchers are tasked with designing a prototype Hyperloop capsule. So far, the TUM team has left their competitors trailing in the dust three times in succession. In fact, TUM students hold the current speed record with an impressive 482 kilometers per hour. Their passion has also generated fresh momentum in the form of a specific research program, supported by funding from the Bavarian state government's Hightech Agenda Bavaria initiative. Among other activities, the project will see students construct a 24-meter-long trial tube and a full-scale prototype of the transport capsule.

Is it possible to travel at speeds in excess of 1,000 kilometers per hour without setting foot on an airplane?

Students at the Department of Aerospace and Geodesy want to make a futuristic means of transport – the Hyperloop – a reality.



Hyperloop research program

Inspired by the passion of our students' initiatives, the Department of Aerospace and Geodesy at TUM initiated the Hyperloop research program. "All areas of our faculty make significant contributions to our Hyperloop research," says Michael Klimke, Managing Director of the Department. Students now work alongside scientists from a wide range of disciplines at TUM with the aim of making their utopian dream a reality.

True Pioneers

TUM launches 70 to 80 technology-based start-ups on the market each year. How does this work?



Convaise

This start-up counted the City of Munich among its clientele soon after was founded and now offers internships to TUM students.

www.convaise.com



EVUM Motors - aCar

20 graduates and 100 students worked on the aCar prototype. This project will soon become a reality, with the first series models now rolling off the production line.

www.evum-motors.com



Hawa Dawa

A start-up using artificial intelligence to fight air pollution? Hawa Dawa is a start-up specializing in the measurement and analysis of airborne pollutants.

www.hawadawa.com



Working to improve the air we breathe: Yvonne Busche and Matt Fullerton from the Hawa Dawa start-up. Their colleagues Birgit Fullerton and Karim Tarraf are seen in the background.

»We started specifically supporting and nurturing founders in the early 2000s.«

DR. ALEXANDROS PAPADEROS

We bring 70 to 80 technology-based start-ups onto the market every year. Talented business founders recall their experiences.

When he was still at school, Tushaar Bhatt already knew what he wanted to be in life: independent and innovative. He comes from a family of entrepreneurs, so even from a young age he was aware of the challenges and risks that lay in his path. After completing his Abitur, Bhatt began to look for a university that suited his aspirations – and the decision was not easy to make. “You can never

perfectly predict whether you will be successful with your business. There are so many incalculables. That’s why I wanted to optimize all the factors I could and create the best possible environment to successfully found a business,” says Bhatt.

In the end, he opted for TUM. “I was impressed by the overall package at TUM: the research, the teaching, a focus on founding businesses, connections to big players from industry, and on top, a business location like Munich. This combination is unique in Germany.”

»The overall package at TUM is unique in Germany: the research, the teaching, a focus on founding businesses, connections to big players from industry, and on top, a business location like Munich.«

TUSHAAR BHATT

TUM worked long and hard to create these offerings. “We started specifically supporting and nurturing founders in the early 2000s,” says Dr. Alexandros Papaderos, Head of Patents and Licenses at TUM ForTe – Office for Research and Innovation. “There have been decisive milestones in our success over the last 20 years: →**UnternehmerTUM**, the incubator and innovation center set up by TUM Honorary Senator Susanne Klatten; the TUM. The Entrepreneurial University vision, and the TUMentreprenurship strategy. They created a new, entrepreneurial attitude and an environment that fosters innovation; this attracts students interested in founding their own business to TUM and actively supports them during their studies, from the idea to founding their business and entering the market.”

Software for improved communication

It soon became clear to Tushaar Bhatt that TUM was the right choice for him. On his Bachelor's degree in information systems, he met two classmates with whom he then launched a project. Together, they developed a program that

facilitates digitalized, automated – and therefore simplified – communication between refugees and the authorities. “For many refugees, the German administrative system and the language represent a barrier. We wanted to simplify the communication and accelerate processes,” says Bhatt. The trio took their project to the US, where they represented North and Central Europe in an innovation competition hosted by the Bill & Melinda Gates Foundation.

When the team returned from the US, it was clear to them that they wanted to found a company together and continue developing their software – and so, →**Convaise** was born. The start-up produces software to facilitate assistant-powered conversational support. They demonstrated just how flexible their product is during the Covid-19 crisis, when it helped to establish swift, digital contact between the City of Munich's health authorities and local residents, distributing information, identifying suspected cases, and facilitating quarantine measures. “Quick and clear communication is important, particularly in crisis situations,” explains Bhatt.

➔ TUM Entrepreneurship Center

From the initial idea through to the growth phase: The TUM Entrepreneurship Center offers a wide range of services and support to technology-oriented founders. This includes the Makerspace, a high-tech workshop, and island workstations in the TUM Incubator.

➔ UnternehmerTUM

With a team of 240 staff dedicated to assisting young founders, UnternehmerTUM supports start-ups from the initial idea through to their stock market launch, offering expertise on setting up their company, entering the market and sourcing funding.

www.unternehmertum.de/en

First and foremost, the Conவை team had the requisite technical experience – but founding a company requires profound business expertise. In addition to the management and technology lectures and seminars integrated in their degree, Tushaar Bhatt and his colleagues took additional courses to prepare them to found a company. “But often, that isn't enough. There comes a point at which you have to bring in additional specialists,” explains Alexandros Papaderos. “We connect students from entirely different areas and assemble them into teams so that they benefit from one another's expertise. We also open doors to our unique network of alumni, enterprises and investors, all of whom support us in founding companies.”

An electric Unimog

Like Tushaar Bhatt, during his studies Sascha Koberstaedt not only found a classmate with whom he wanted to found a business, but also came up with the idea that would help him become self-employed while simultaneously doing a service to society: a sustainable utility vehicle for developing and emerging countries. “We wanted to develop a robust vehicle without all the bells and whistles and with high ground clearance for poor road conditions. An electric drive system was therefore important to us, as it provides a lot of momentum when driving off. It also emits less carbon dioxide than an internal combustion engine and has lower operating costs,” as Koberstaedt explains. Over the course of the project, 20 graduates and 100 students at TUM worked on what would ultimately become the ➔aCar, including four students from Ghana. “Their input was enormously

important. We didn't want to produce a vehicle for people in Africa, but together with them,” says Koberstaedt. “There's nothing more sustainable than building up local markets. We want the vehicles to be manufactured locally, with all rights and obligations.”

In 2017, this project became a business. A lot has happened since then. The start-up has continued to grow and now employs over 50 members of staff. Investors and companies have become aware of the aCar. Demand has been high, including in Germany, as farmers, forest rangers and gardeners discovered the car's benefits – which led to the car initially being launched on the German market.

Data for smart green cities

➔Hawa Dawa is another start-up with its origins at TUM and the goal of doing good. The name says it all: Hawa Dawa means “air purity”, or something to that effect, in seven languages. Its founder, Karim Tarraf, engaged with the topic from an early age. He was raised in Cairo, a city with alarmingly high levels of air pollution. His parents are both specialist lung doctors, while his brother suffers from asthma.

During his Master's in management and technology at TUM, Karim Tarraf took part in the interdisciplinary hands-on course “THINK.MAKE.START.”. Within two weeks, he and his fellow participants developed a portable measurement device that shows people with asthma the current level of air pollution.

➔ Munich Urban Colab

UnternehmerTUM's new creative quarter is under construction in Munich's Schwabing district. Across five stories and a total surface area of 11,000 square meters, it will offer space for workshops, fitness rooms, winter gardens and, most important, over 250 start-ups.

www.unternehmertum.de/en/about/munich-urban-colab

➔ TUM Venture Labs

Fostering entrepreneurial spirit and entire families of start-ups in key technological fields and thereby positioning the Munich metropolitan region as the European leader for new company foundations are the goals of the new TUM Venture Labs.

»We wouldn't be here without TUM; it provides truly fertile ground on which to found a company.«

YVONNE RUSCHE

This marked the birth of initial idea. After completing the course, Tarraf found the team with whom he wanted to found a business. This included his wife, Yvonne Rusche, and another married couple who primarily brought technical expertise to the start-up: Birgit Fullerton, a data scientist, and Matt Fullerton, a system architect. Together, they worked at the **MakerSpace** high-tech workshop, developing a new solution to comprehensively depict air quality in real time.

So, how does it all work? Hawa Dawa collates data from existing sources, such as satellites and public measurement stations, and integrates them in an online platform. The start-up's own measurement stations supplement the existing network of sources. All of this data is then analyzed by Hawa Dawa's measurement device, which is smaller and less expensive than public measurement stations. "We use calibration algorithms that take into account the interactions between pollutants and the influences of temperature, air humidity and air pressure in order to eliminate disruptive factors from the data," explains Yvonne Rusche.

City administrations have shown a particular interest in this air quality data, with a view to developing new concepts, such as for transport. The company, which now employs around 20 members of staff, is steadily expanding its range of customers.

Fertile ground on which to found a company

These young entrepreneurs are glad to have studied and founded companies at TUM. "We wouldn't be here without TUM; it provides truly fertile ground on which to found a company," says Yvonne Rusche.

Sascha Koberstaedt, too, emphasizes just how important it was that the aCar project started at TUM. "You can't develop a car as a lone individual. Without the research work and knowledge of TUM, we certainly wouldn't have been able to get the business going."

Tushaar Bhatt agrees. "The UnternehmerTUM incubation and innovation program was particularly helpful in making Convaize a reality,"

**»Thanks to UnternehmerTUM,
we were able to hone our
specialist knowledge for
product development as well
as our entrepreneurial
expertise. «**

TUSHAAR BHATT

he says. "It allowed us to hone our specialist knowledge for product development as well as our entrepreneurial expertise." The intensive exchange with TUM endures to this day; six TUM students are currently working at Convaire and learning how an idea can become a business.

UnternehmerTUM facts and figures

5,000+ participants
per year

50+ scalable start-ups
per year

100+ innovation
partners per year

© Source: <https://www.unternehmertum.de/en/about/daten-fakten>

The Next Big Thing

Significant Market Opportunities

The TUM Venture Labs initiative establishes high-tech incubators at interdisciplinary interfaces

»In recent years, we had an average of 70 to 80 spin-off companies a year. That puts us on course to become the European frontrunner.«

DR. ALEXANDROS PAPADEROS

Unique strengths of TUM/UTUM Ecosystem

Inventions are the progeny of research. In the best case, they also serve to support business and industry. Alexandros Papaderos, who has helped to conceive and establish the Venture Labs at TUM, and his team at TUM ForTe work to ensure that every invention and business idea born from research is visible for companies, which can then be used and developed further. In the past, many scientists were still not used to giving thought to the commercial use of the results of their research, particularly founding a company based on it. "Today, many of our students and researchers do so as a matter of course," says Papaderos. "In recent years, we had an average of 70 to 80 spin-off companies a year."

The TUM Venture Labs initiative has been established by TUM and UnternehmerTUM with the support of partners from other institutions and companies with a view to further improving both the quantity and quality of spins-offs from TUM. TUM

Venturing

Network & Events



Space & Tools

Education

Venture Labs make wide-ranging offerings available to interested students who are open to new ventures. It is hoped that supporting these newly founded companies will establish both TUM and the Munich region as a European technology hub. "With the TUM Venture Labs, we have set up subject-specific, cross-functional and interdisciplinary incubators in the schools," says Papaderos.

For example, while a start-up team focusing on the field of agriculture and food might be situated at the TUM Venture Lab at the TUM School of Life Sciences in Weihenstephan, they can also discuss issues relating to big data with the TUM Venture Lab for AI/Software. "In doing so, we are facilitating new and more efficient networking," says Papaderos. "It expands both our activities and our knowledge." And, in an ideal scenario, it will also lead to more scientists and students feeling emboldened to found their own companies in future.

Social, economic & technological Mega Trends

The people whose pioneering spirit, talent and creativity fill our university with life are the beating heart of TUM, as are the numerous individuals who support them in achieving their ambitions in research, teaching and innovation.

Generations of students and talented scholars have become global ambassadors for our university and made us into one of the most outstanding technical universities in Europe. Many of them play an active role in our alumni network and have maintained a connection with their alma mater, dynamically supporting our future viability and expanding our scope of action in a way that would not be possible through state funding alone. Together with responsible companies and foundations, they support TUM's strategic efforts and supplement our university's creative power.

The opportunities to become involved are as diverse as our university itself. Our supporters can play their part through the TUM University Foundation or launch innovative projects themselves to become a driving force of modernization. The open exchange between science, business, politics and society in our visionary programs allows our supporters to simultaneously share in our university's expertise and experience for themselves the impact of their commitment to TUM.

Our Supporters

How foundations, businesses and private individuals support TUM

There are a multitude of reasons to become involved:

Getting the youngest enthusiastic about nature and technology

through the Student Research Center at Berchtesgadener Land or the Friedrich N. Schwarz Teaching and Research Station at the heart of Berchtesgaden National Park.

Attracting the most promising talent

through scholarship programs for young researchers and renowned academic talent.

Securing the future of our business location

by supporting entrepreneurs at TUM and creating a promotion structure and infrastructure like no other in Europe.

Supporting our parents and campus kids

by establishing daycare centers and childcare facilities for the children of our students and staff.

Overcoming our own conceptual limitations

through encounters at the Science & Study Center in Raitenhaslach, where students and researchers can exchange ideas and establish a dialog with the worlds of politics, business and society in a former Cistercian monastery.

Finding solutions to future problems

through innovative approaches to research into digitalization or medical topics, such as containing the coronavirus pandemic, treating cancer, and investigating neurological diseases like multiple sclerosis.

Promoting talented students

through the German Scholarship, in which the federal government doubles every donation made. We currently support more than 700 of our 43,000 students through this scholarship, helping them to focus more single-mindedly on their studies, unleash their greatest potential, and benefit from the experience of our supporters in their functions as mentors.

→ Further information

www.fundraising.tum.de/en

www.tum-universitaetsstiftung.de/en

Thank you!

Our thanks go out to all our students, professors, scientists, researchers, alumni, corporate partners, donors, supporters and everyone who works at TUM. Together, we are making our world a better place.





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