Fraunhofer ITWM

Fraunhofer Institute for Industrial Mathematics ITWM

Annual Report 2021/2022

Mathematics Makes Mobile – For 25 Years

25 JAHRE
FRAUNHOFER ITWM
IN KAISERSLAUTERN

Cover

Our cover picture connects the topic »mobility« with the 25th anniversary of the Fraunhofer ITWM: In order to draw attention to the anniversary, a city bus in the Fraunhofer ITWM look drives through Kaiserslautern.

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Mobility – A Field of Research With Many Facets

Dear readers,

mobility is a central achievement of our society; it guarantees us freedom and brings us closer together globally in many areas. But it comes at a price and requires a lot of energy. This also makes it a significant factor in a prominent issue of our time, climate change.

Our Annual Report 2021/2022 focuses on the topic of "mobility". First and foremost, we want to demonstrate our expertise in this area and present the research projects that address various aspects from different perspectives.

For us, moreover, the theme for 2021/2022 has particular symbolic power: Despite the ongoing Corona pandemic, significantly more movement was possible again. Mobility is therefore not only of professional relevance for us, but this year it also stands for the recovery of the accustomed everyday life.

We at the Fraunhofer ITWM deal with many facets: This concerns first of all our large department "Mathematics for Vehicle Engineering". Many other departments also deal with specific aspects – from the maintenance of trains to the storage of energy for the opera-

tion of electric vehicles to the dispersion of aerosols in airplanes and the optimization of public transport. With our research, we contribute at very different points to the further development of mobility in a future-oriented way.

As the AI Pilot for Mobility of Rhineland-Palatinate, I advise science and companies together with my advisor Dr. Henrike Stephani on how they can incorporate artificial intelligence (AI) into their processes. We make our know-how accessible to science, business and industry, present projects and methods that use AI particularly successfully in the field of "mobility" and thus want to enable the use of AI where added value can be expected. This is an exciting transfer that we have enjoyed driving forward in recent months.

The mobility industry is one of the defined lead markets of the Fraunhofer-Gesellschaft. We contribute to many other sectors and, as in the previous year, our annual report is structured according to these. You also learn about our current projects for the lead markets of health and medicine, digitization, energy, mechanical engineering, and process engineering, as well as about the strategic research field of quantum technology.

The passion for science and research has united us at Fraunhofer ITWM for 25 years now – 2021 was our anniversary year. Due to the pandemic, the activities around this event, which is significant for us, turned out to be smaller than we had imagined. Nevertheless, we have managed to recognize and celebrate the successes of a quarter of a century. Naturally, we are also devoting attention to this special birthday in our annual report – and linking the anniversary to the theme of "mobility" on our cover.

I wish you an enjoyable read with profitable insights. If you have any questions, please do not hesitate to contact us at Fraunhofer ITWM. Please do not hesitate to contact the mentioned persons of our institute either!

Kind regards

Prof. Dr. Anita Schöbel

Content

The Institute in Profile

Computer simulations are indispensable in designing and optimizing products and processes. Real models are replaced by virtual models. Mathematics plays a fundamental role in the development of this digital world. It is the technology that generates these images and efficiently converts them into software, the raw material of models and the core of every computer simulation.

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Million euros Budget – Networking pays off

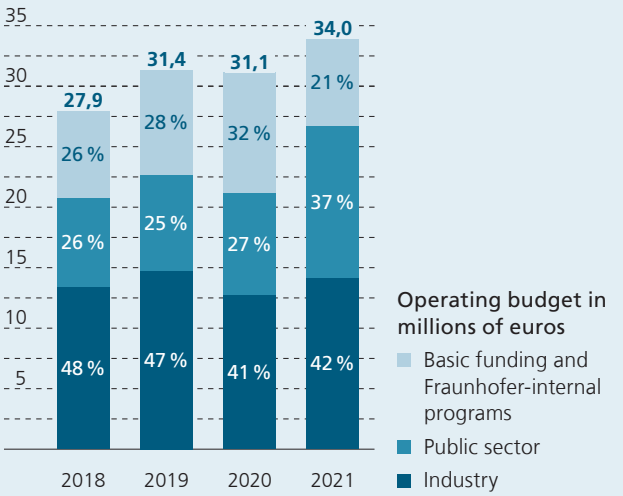
Applied Mathematics as a Key Technology

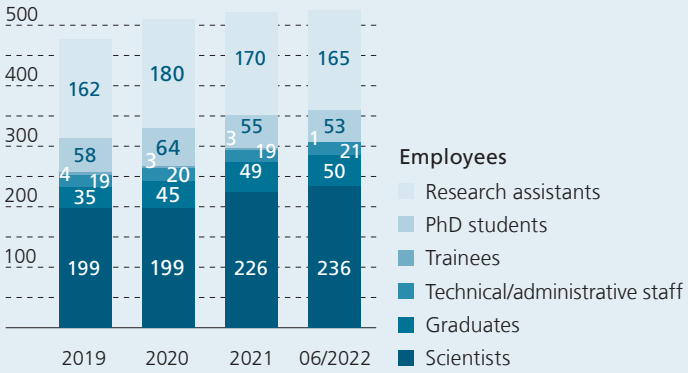
Many small and medium-sized companies use simulation to reduce costs. We support these companies in particular with consulting and computing power. They profit on the market through the use of simulation in terms of innovation and quality assurance of products. Of course we also work with large companies, especially in the automotive industry, mechanical engineering, the textile industry, microelectronics, the computer industry and in the financial sector. Integral components of our research and development projects are consulting and implementation, support in the application of high-performance computing technology and provision of customized software solutions. We not only use simulation software, but develop it ourselves, often in cooperation with leading companies.

Our versatile core competences

- Processing of data from experiments and observations
- Setting up mathematical models
- Conversion of the mathematical problem solutions into numerical algorithms
- Summarizing data, models and algorithms in simulation programs
- Optimizing solutions in interaction with the simulation
- Visualize simulations

As Fraunhofer ITWM we do not only want to be the bridge between the real and the virtual world, but also to build a link between university mathematics and its practical implementation. Therefore, the close connection to the Department of Mathematics at the University of Kaiserslautern plays a special role.





Industries – who do we work for?

The competencies of our departments and the broad spectrum of their application fields are used in numerous industries.

With our core competencies in the areas of modeling and simulation, optimization and decision support, data analysis and visualization, we address companies and organizations in the following industries:

- Process engineering, Mechanical/plant engineering
- Automotive industry and suppliers
- Medicine and medical technology
- Energy and raw materials industry
- Technical textiles
- Information technology
- Finance industry

Through many years of cooperation with our regular customers, we have developed a strong domain competence in subsectors of individual industries. The following applies to all industries:

The modeling and simulation competence of the Fraunhofer ITWM generates real competitive advantages on the market.

Board of Trustees

- Prof. Dr. Nicole Bäuerle, Karlsruhe Institute of Technology
- Prof Dr. Peter Benner, Max Planck Institute for Dynamics of Complex Technical Systems
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- Stefanie Nauel, Ministry of Economics, Transport, Agriculture and Viticulture of the State of Rhineland-Palatinate
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- Prof. Dr. Arnd Poetzsch-Heffter, President of the TU Kaiserslautern (Current Chair)
- Dr. Udo Scheff, John Deere GmbH
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- Dr. Carola Zimmermann, Ministry of Science and Health of the State of Rhineland-Palatinate

(Status: September 2021)

Networking in the Fraunhofer-Gesellschaft

A large network and bright minds are crucial for the success of projects. Our specific mathematical competencies make us a sought-after and valued cooperation partner within the Fraunhofer-Gesellschaft.

Fraunhofer Alliances
Related institutes organize themselves into research alliances and operate jointly in the R&D market. They participate in the corporate policy as well as in the implementation of the functional and financing model of the Fraunhofer Gesellschaft. The Fraunhofer ITWM is a member of the Alliance for Information and Communication Technology IUK and has guest status at the Alliance MATERIALS.

Fraunhofer Cluster of Excellence
These clusters promote the cooperative development and processing of system-relevant topics through a cross-institutional research structure spread across several locations. We are involved in the following clusters:

- Fraunhofer Cluster of Excellence Advanced Photon Sources CAPS
- Fraunhofer Cluster of Excellence Cognitive Internet Technologies CCIT
- Fraunhofer Cluster of Excellence Programmable Materials CPM

Fraunhofer Strategic Research Fields
They bundle the essential future fields of application-oriented research. Institute Director Prof. Dr. Anita Schöbel is the spokesperson for the Fraunhofer Strategic Research Area "Next Generation Computing" and, together with Prof. Dr. Manfred Hauswirth (Fraunhofer FOKUS), is responsible for the topic of "Quantum Computing" at Fraunhofer. The Rhineland-Palatinate competence center focusing on "Quantum High Performance Computing" is located at our institute.

Lead Market-Oriented Alliances
With the defined lead markets, Fraunhofer pursues the goal of addressing industries with high relevance for innovative strength and creating added value through offers for system solutions and cross-institutional transfer. The most important for us are:

- Plant, mechanical and vehicle construction
- Health care industry
- Chemical industry
- Mobility economy
- Digital economy
- Energy industry

Fraunhofer Lead Projects: Preliminary Research in the Group
Thematically, they are oriented to current fields of industry and bundle the competencies of different competencies of various institutes for efficient preliminary research.
Leading projects with ITWM participation are currently:

- ML4P – Machine Learning for Production
- QUILT – Quantum Methods for Advanced Imaging Solutions
- COGNAC – Cognitive Agriculture
- ShaPID – Shaping the Future of Green Chemistry by Process Intensification and Digitalization
- SUBI²MA – Sustainable, Simulation-guided Biobased and Biohybrid Materials

FCC – Strong Partnership in Sweden
One of our most important international partners is the "Fraunhofer Chalmers Research Centre for Industrial Mathematics", or FCC for short, founded in 2001 by the Fraunhofer Gesellschaft and Chalmers University in Gothenburg. In 2021, 61 employees worked on topics such as multiphysics simulation, geometry, modeling of biological systems and data mining. The budget was just under 7 million euros.

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Trade fairs and events

Center of Excellence Simulation and Software-Based Innovation

HIGH PERFORMANCE CENTER
SIMULATION AND SOFTWARE-BASED INNOVATION

Digital solutions are driving energy-efficient and resource-conserving production decisively. To this end, new results and ideas must be transferred into practice as quickly as possible. This is one of the central tasks to which the Simulation and Software-based Innovation Center is dedicated. In the so-called transfer centers of the high performance center, the scientific results of research are transformed into innovations and requirements from industry and society are directly addressed.

The Fraunhofer ITWM and Fraunhofer IESE, the TU Kaiserslautern, and the Kaiserslautern University of Applied Sciences bundle their competencies in the performance center. In addition, there is a cooperation with the German Research Center for Artificial Intelligence DFKI and the Leibniz Institute for Composite Materials IVW as well as other associations and initiatives. The cooperating companies from the business community include more than 30 regional and at least as many national companies. Among others, BASF, Daimler Trucks, BioNTech and John Deere are involved in the development work.

Fit for the Future With a New Structure

The performance center is divided into research and development labs and transfer centers. The R&D labs work methodically and develop concepts and algorithms as basic technologies for the transfer centers. After six years of successful research and transfer work, the time has come to tackle new problem areas in 2022. The existing R&D labs and transfer centers have been expanded and realigned in terms of content. The three new R&D labs "Digital Twins," "Data Analysis and Artificial Intelligence," and "Next Generation Computing" are dedicated to the digitization of products, the challenges of AI in practice, and new computer and memory architectures for embedded systems and for high-performance computing. The four transfer centers "Process Engineering/Chemistry", "Mobility", "Production Processes/Energy Efficiency" and "Biotechnology/Health" focus on the exploitation of the methods in the industry.

Research on the Pulse of Time

"With the new structure of the performance center, we keep our finger on the pulse of the times", says Dr. Konrad Steiner, department head at Fraunhofer ITWM and managing director of the performance center. "The new thematic orientation ensures that we target the future topics which are of highest relevance for industry and society now and in the next years." Base funding of one million euros annually has been secured from the Fraunhofer Gesellschaft. The total annual budget of more than 10 million euros is supported by funding projects from the state of Rhineland-Palatinate and primarily by industrial projects.

Contact

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More information at www.leistungszentrum-simulation-software.de/en

Spin-Offs and Other Collaborations

Spin-Offs of the Fraunhofer ITWM

- **fleXstructures** – specific engineering projects and services for the simulation of flexible components
- **Math2Market** – comprehensive software services, such as GeoDict®, an innovative simulation software for digital materials research and development
- **Product information office for old-age provision PIA** – neutral body for the opportunity risk classification of subsidized retirement provision products
- **Sharp Reflections** – Big-Data computing technologies for the future of seismics
- **ThinkParQ** – fast and scalable solutions for all performance-oriented environments such as HPC, AI and Deep Learning
- **Wendeware AG** – software ecosystem for the energy transition

Promotion of Young Talent

The **Felix Klein Center for Mathematics (FKZM)** is an institutional connection between the Department of Mathematics of the TU Kaiserslautern and the Fraunhofer ITWM. The focus is on the promotion of young scientists, for example with modeling weeks for schools, scholarships, and a mentoring program for mathematics students. Scholarship holders are not only supported financially, they can also combine practice and theory. Students in advanced semesters and doctoral students can take part in advanced training courses lasting several days, and they can also listen to lectures by top-class researchers. The monthly "Thinking outside the box" of the Felix Klein Center offers interesting insights into different topics from science and culture.

The Competence Center for Mathematical Modeling in STEM Projects in Schools (KOMMS) is primarily aimed at teachers. It is located at the TU Kaiserslautern and combines the areas of school projects, education and training, and research.

The national **Excellence school network MINT-EC** aims to get students excited about STEM subjects. In the course of the cooperation, regular events such as the Math Talent School are offered.

Embedded in the Location

The **Science and Innovation Alliance Kaiserslautern (SIAK)** forms a network for digital transformation, innovation and interdisciplinary research. It is regionally anchored through its members from science (universities and research institutes) and business, especially from small and medium-sized enterprises.

Networking in Europe

In the **European Consortium for Mathematics in Industry (ECMI)**, scientific institutions and industrial companies in Europe have joined forces with the aim of bringing mathematical modeling, simulation and optimization even more strongly into economic application. An important role is played by the training of industrial mathematicians, because their expertise in particular is used.

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new jobs have been created by our Spin-Offs

More information at www.itwm.fraunhofer.de/networks

2021: A Quarter of a Century Fraunhofer ITWM

25 JAHRE
FRAUNHOFER ITWM
IN KAISERSLAUTERN

For 25 years, we have been using mathematics as a key technology to optimize products and processes. Founded in January 1996 as a state institute, Fraunhofer ITWM has proven itself as a place of innovation and was incorporated into the Fraunhofer-Gesellschaft in 2001. In the meantime, it has become one of the largest mathematical research institutes worldwide, also thanks to intensive networking, regionally as well as internationally.

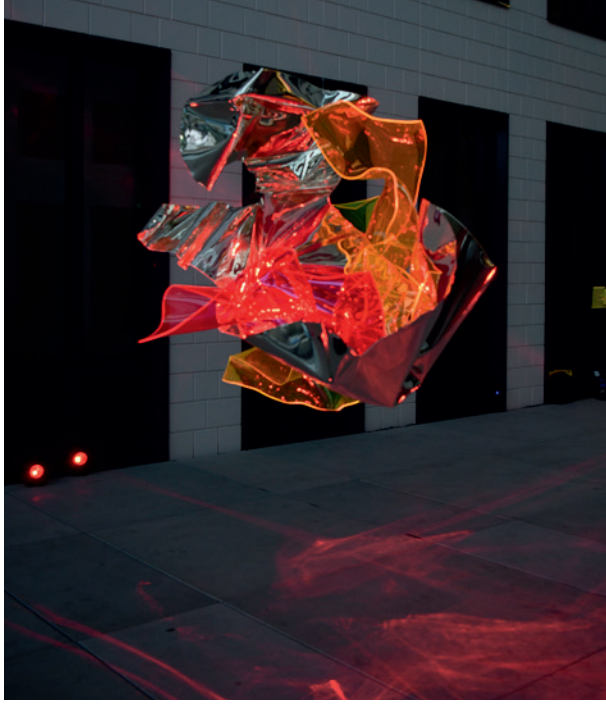
The anniversary year was held under the motto "GrowingTogether. The motto can be read in different ways and refers both to the joint growth, the expansion of our institute, and to the coming together and growing together with partners such as the TU Kaiserslautern, the city itself, and many local research institutions. We are proud of this and look forward to the challenges of the coming years.

Mathematical Diversity Also Visible to the Outside

Especially the passers-by of the Trippstadter street in Kaiserslautern might have noticed them: Colorful window pictures with slogans like "Math makes you rich", "Math is hot", and "Math fills you up" have been decorating the facade of the Fraunhofer ITWM since March 2021. Behind these 25 posters, digital "little doors" are hidden, which lead to project websites of our departments. An exciting insight into our institute, illustrating the thematic range of our nine departments. Our anniversary was not only noticeable right on our own doorstep, but throughout the city!
On the streets of Kaiserslautern, a bus is still driving today, which – completely wrapped in the Fraunhofer design – in addition to the large number 25 in thick letters also announced our motto for the year 2021: "GrowingTogether.

Combining Science and Art

A particularly vivid contribution to the anniversary year was the light and sound installation "Brainpatterns" in the atrium, which scientifically interested and art lovers could experience after dark in September. Through the glass front of the institute, one could see an organically intertwined sculpture made of acrylic



elements, which glowed in a colorful play of colors from the inside and created the impression of an artificial intelligence. Parallel to this visual staging, viewers were able to connect to a synchronized sound installation via QR code and smartphone, which added a second sensory level to the action. The artwork was created by the artist Tatjana Busch, in cooperation with the media studio "E".

Light Installation Impresses

Behind this visual and acoustic spectacle is the interdisciplinary project "Brainpalace – Brainpatterns", which explores the potential of combining art and neurofeedback. The approach in the first part of the project "Brainpatterns" was to measure brain activity in the course of perceiving an audiovisual and spatial light installation: parameters were extracted from EEG signals and then fed back to the installation as feedback. This created an interactive interaction between the viewers and the artwork, whose play of colors reacted to these signals. In "Brainpalace", the second part of the project, these measurements were to be extended to whole groups of spectators at Fraunhofer ITWM.

25 years of success with mathematics: The year was heralded with waving anniversary flags and was accompanied by numerous activities: 25 math motifs were dedicated to the exciting ideas of our researchers. The light installation could be admired as a highlight in the fall. Here, computer simulations of the Fraunhofer ITWM were turned became real art.

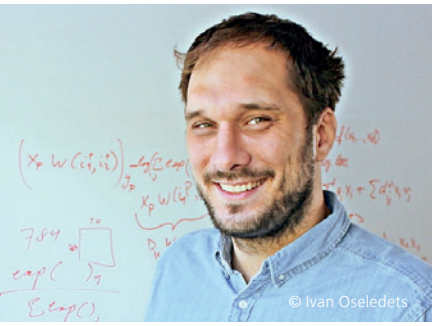
www.itwm.fraunhofer.de/en/25

Review: Highlights 2021

ECMI: Machine Learning and Big Data for Cable Simulation

Our area "Mathematics for Vehicle Engineering" is involved in ECMI – the European Consortium for Mathematics in Industry – 2021, among other things with the webinar "Math for Industry 4.0 – Models, Methods and Big Data". The focus was on "cable simulation" and "digital human modeling". With the software package IPS Cable Simulation, an established tool for the simulation of cables and hoses, we are well positioned here.

www.itwm.fraunhofer.de/ecmi-online-conference



Guest at the Fraunhofer ITWM: Prof. Ivan Oseledets

Humboldt Award Winner Prof. Ivan Oseledets at the Fraunhofer ITWM

The Humboldt Society for Science, Art and Education promotes worldwide scientific exchange, including research stays in Germany. Ivan Oseledets, professor at the Skolkovo Institute of Technology in Moscow, received one of the coveted fellowships for a stay at our institute. He is no stranger here: Oseledets works with the "Optimization" department as well as the "Flow and Material Simulation" department. His areas of interest are "Big Data and Artificial Intelligence (AI)", which is why he is involved in industrial projects at the institute to model various physical processes using AI technologies and Machine Learning (ML).

www.itwm.fraunhofer.de/Oseledets [only available in German]

Dr. Franziska Diez receives GAUSS Young Investigator Award for outstanding doctoral thesis.

Awards for Outstanding Research in Financial Mathematics

Two honors went to " Financial Mathematics" in 2021: Prof. Dr. Ralf Korn, ITWM consultant and member of our Scientific Advisory Board, was elected Chairman of the German Society for Insurance and Financial Mathematics (DGVFM), and our colleague Franziska Diez received the GAUSS Young Investigator Award. Every year, the DGVFM and the German Actuarial Association (DAV) award three GAUSS Young Investigator Awards for outstanding scientific work. Franziska Diez, a researcher in the "Financial Mathematics" department, was honored for her dissertation. The thesis on "Yield Curves and Chance Risk Classification: Modeling, Forecasting, and Pension Product Portfolios" was particularly praised for its impressive combination of theory and application in the field of pension products.

www.itwm.fraunhofer.de/gauss_prize

Prof. Dr. Anita Schöbel Becomes President of the European or Societies

In July 2021, the Council of the Association of European Operational Research Societies (EURO) unanimously elected our institute director as its new president. The EURO is the European section of the "International Federation of Operational Research Societies" (IFORS) and aims to promote Operations Research (OR) throughout Europe.

Anita Schöbel researches and teaches in the field and especially emphasizes the application aspect: "For me, Operations Research is an important research topic at the university, but also in the practice of Fraunhofer ITWM. We use OR methods in many projects, such as in healthcare, logistics, production or energy optimization."

www.itwm.fraunhofer.de/euro-president

Targeted Assistance in the Event of a Disaster

In a disaster, every second counts to care for those in need. The teams of relief organizations have to find their way very quickly in devastated areas. Researchers in our "Image Processing" department are developing a software that gets humanitarian aid to the right destination faster. They are using drone images that are analyzed in real time with artificial intelligence (AI). The scientists are combining specially developed image processing and deep-learning algorithms to enable fully automated analysis of the drone images. In order for the artificial intelligence to start the independent learning process, it is "fed" with data. For this purpose, the researchers draw on satellite imagery from earthquake zones, for example. The system works without an Internet connection and on commercially available notebooks and can therefore also be reliably used in devastated areas without infrastructure.

Drones provide image data on the extent of the disaster in a short time.

www.itwm.fraunhofer.de/edda-pm-en

International Exchange at KLAIM – Kaiserslautern Applied and Industrial Mathematics Days

A new event format brought together many researchers in October 2021 after a long hiatus: More than sixty international scientists accepted the invitation of Prof. Dr. Anita Schöbel and Prof. Dr. Bernd Simeon from the Department of Mathematics at TU Kaiserslautern. The KLAIM conference provides a forum for mathematicians from universities, research laboratories, and industry to exchange ideas and present the latest results. The first edition of KLAIM focused on the role of applied mathematics in the development of digital twins. Forty short talks and extensive discussion sessions provided a multifaceted look at the topic. In the future, the conference will be held every two years.

www.itwm.fraunhofer.de/klaim-pm-en

New Work – This Is How We Work at the Fraunhofer ITWM

Hybrid conferences are part of our new everyday working life. Some employees are already booking shared office space. some employees already do.

The research of the Fraunhofer ITWM shapes the future in many areas. The working environment must be right in order for our employees to achieve top results together with their research partners. The way to this is paved by our "New Work" team, which deals with modern working.

The Corona pandemic changed the working world from one day to the next and thus became an endurance test with respect to topics such as mobile working, online meetings, and leading at a distance. The "New Work" team is concerned with permanently designing the conditions at Fraunhofer ITWM in such a way that there is plenty of room for research activities and creative thinking, and at the same time the needs of the individual employee can be reconciled with the requirements of the teams in the best possible way.

Back at the Institute – But More Flexible

"Over the past two years, our employees have shown that they can shape their working environment individually without teamwork internally or collaboration with external parties falling by the wayside," says Institute Director Prof. Dr. Anita Schöbel, looking back on the experience of the Corona pandemic. "Even though we are very happy about the return to the institute and to the more familiar working environment with many personal encounters, we want to maintain a certain flexibility that we have tested. So, we offer an agile, modern work environment at the Institute."

The "New Normal" is being tested at Fraunhofer ITWM with a company agreement that combines the advantages of familiar and new forms of work. This was developed based on an online survey of the "New-Work" team and revealed: The majority of the employees at Fraunhofer ITWM would like to work mobile at least two days per week. This was mainly justified by the advantages of time savings, flexibility, and concentrated work. Disadvantages of mobile working were seen in the loss of contact with colleagues, the loss of work-life balance, and the fact that too many online meetings were held.

Working with a child is possible on site at the Fraunhofer ITWM since many years already in the parent-child office

Share Management Tasks

However, "Working World 4.0" involves more than just questioning time and space constraints. Due to the strong growth of the institute in recent years and the simultaneous increase in working from home, topics such as the sharing of workplaces and new communication formats are also coming into focus. In addition, the demands on managers and their wishes for the design of their tasks are changing.

One example is the topic of "shared leadership," which the "High Performance Computing" (HPC) area is already living. Step by step, the tasks performed here by long-time head Dr. Franz-Josef Pfreundt have been transferred to several shoulders. "HPC consists of many different groups that work very independently. With the retirement of our division manager due to age, the question arose as to how the HPC would position itself in the future," says Matthias Klein-Schlößl, head of the "Green by IT" team, explaining how the division's multi-member management team came about. "We feel we belong together and therefore wanted to remain as one unit," he says. "The result is the "F-Team," in which eight executives are each responsible for specific focus areas, such as finance or science management. The process is very democratic: "We make decisions that affect everyone together and strive for a unanimous vote here," says Klein-Schlößl. "We've done very well with that so far!"

Increase the Proportion of Women at the Institute

New working and organizational models are considered by experts to be important factors for equal opportunities. They are thus a lever for more diversity and equal opportunities; a significant topic also at Fraunhofer ITWM: "We want to win more women for us, because the STEM subjects and especially mathematics with their versatile applications are an exciting field of work for everyone," emphasizes Schöbel. "We offer an environment that makes it possible to balance research and family well, and we want to make even more possible."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C 9
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Mathematics Makes Mobile – Intelligent and Sustainable

The topic of "mobility" has accompanied us at Fraunhofer ITWM since the beginning, which is why we have a large number of exciting projects in this area – across all departments. Even before artificial intelligence became a buzzword, we developed methods to optimize mobility for providers and users, regardless of the mode of transport. Whether rail, car, commercial vehicle or airplane: In the past 25 years, we have included all means of transportation in our research portfolio.

The ITWM-Technikum: Link Between Reality and Simulation

In system and vehicle development, it is key to simulate the physical system properties at an early stage in each of the different phases of the development process. To design, validate and improve new methods, we have special test facilities on site: In the Technikum of the division "Mathematics for Vehicle Engineering", we design and implement our own measurement and testing facilities, hand in hand with our modeling and simulation experts.

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Projectors provide all-round visibility

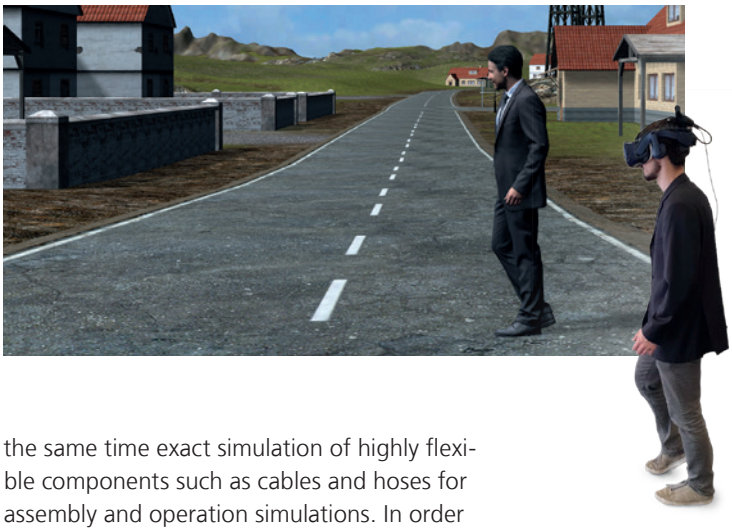
In the Technikum, we develop, set up and operate our robot-based driving simulator RODOS®, our measuring system for highly flexible components (MeSOMICS®), the 3D laser scanner measuring vehicle REDAR as well as various test benches for cable and hose measurement.

The driving simulator RODOS® (Robot based Driving and Operation Simulator) allows to examine the human machine interaction under perfectly reproducible conditions and without any risk. Designed for a payload of 1,000 kilograms, the motion system (an industrial robot) carries commercial vehicle cabs and car bodies. Inside a ten-meter diameter projection dome, 18 projectors create a seamless projection of an interactive scene. For example, we investigate the interactions between drivers, the vehicle and the environment and validate advanced driving assistance systems together with industry partners. RODOS® is currently the most powerful driving simulator of the Fraunhofer-Gesellschaft.

Take a Walk in VR

Our virtual reality lab enables people to put themselves into complex virtual environments and scenarios, e.g. as pedestrians.

We use the technology both for coupling with driving simulation and for visualizing virtual production sites. In our lab, one or more people experience a virtual reality on a surface of ten by six meters.



Valid Data Thanks to Precise Measurement Technology

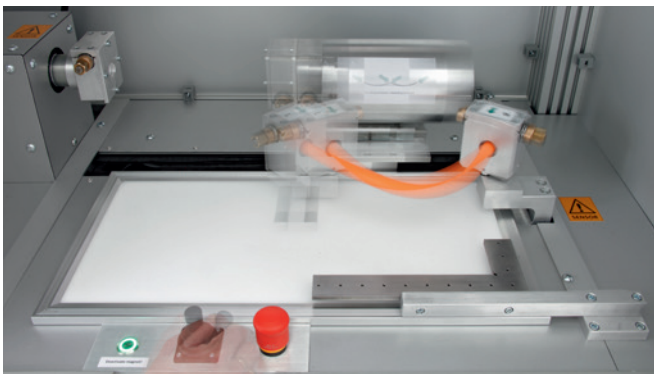
Numerical simulation of real systems or components generally depends on two things:

- On the one hand, a good mathematical model of the system is mandatory to obtain usable simulation results.
- On the other hand, the model must be fed with the correct parameters that also correspond to the real conditions. Often the determination of these parameters is difficult and has to be done individually for each new situation.

The same is true for the IPS Cable Simulation software developed by Fraunhofer FCC and our institute. This enables interactive and at the same time exact simulation of highly flexible components such as cables and hoses for assembly and operation simulations. In order to correctly calculate the deformations and reaction forces of cables and hoses with IPS Cable Simulation, it is necessary to determine the mechanical component properties as model parameters.

For this purpose, the ITWM team has developed, designed, built, and applied for a patent for a highly automated measuring machine (MeSOMICS®) in the Technikum.

MeSOMICS® stands for "Measurement System for the Optically Monitored Identification of Cable Stiffnesses". It is a measurement system for the identification of effective cable stiffness properties.



Bending and curving – the MeSOMICS® measuring machine quickly and easily determines cable properties as they occur later in the vehicle. The measurement runs automatically. Employees simply clamp the cable and start the system.

www.itwm.fraunhofer.de/technikum_en

Contact

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Plan – Control – Regulate Traffic Flows

What makes public transport attractive? In view of the rising cost of gasoline and the desired energy transition, creative and sustainable answers to this question are essential. A research group in our division "Mathematics for Vehicle Engineering" is investigating how public transportation pays off for companies and passengers. At the same time, it is also looking at individual transportation: The goal is flow instead of standstill.

The Opel traffic circle in Kaiserslautern is a traffic junction that often impedes the flow of traffic. The Fraunhofer ITWM provides suggestions for the optimization.

Bus and rail passengers want reliable connections, high frequency rates and low fares. Transport companies must operate economically and sustainably: In addition to being attractive to their customers, they also have to consider operating costs and the resulting environmental impact.

LinTim Expands the VMC®-Family

"An optimal traffic system consumes as little energy as possible, covers all needs at the same time and also allows traffic to flow," says project manager Dr. Michael Burger, describing the noble goal. "With our methods and tools from the 'Virtual Measurement Campaign' (VMC®) software family, we can simulate and model individual road traffic highly efficiently, and now we're adding public transport to the mix. That's why we integrated the LinTim software into our VMC® family." The tool was originally developed in the working group of our institute director Prof. Dr. Anita Schöbel.LinTim stands for "Lineplanning and Timetabeling," but it can do much more than lines and timetabling. VMC® LinTim includes algorithms for stop, line, circulation and trip planning, as well as delay management. In addition, it can analyze, assess and optimize the energy demands of deployed vehicles depending on the environment. All methods are integrated into a library and can interact with each other in the various planning stages. VMC® LinTim therefore also finds solutions that are not visible with classical approaches. "In this way, we support traffic planners who, up to now, have mostly used their empirical knowledge as a basis for planning," says Michael Burger.

Simulations Reduce Downtime

In a simulation study, Burger's team is also investigating traffic flows and traffic light control at the Opel traffic circle in Kaiserslautern – a traffic junction in the west of the city that connects the industrial park, highway and bypass. The neuralgic point combines a traffic circle with a traffic light system and regularly produces traffic jams. Our researchers were able to show that an adapted traffic light control – based on traffic data, models and modern mathematical methods – offers great potential for significantly higher flow rates. The tool was developed in the working group of our institute director Prof. Dr. Anita Schöbel.

VMC LINTIM

What New Drive Concepts Do We Need?

Vehicles are on the road for a variety of reasons. Environmental data, models and simulations based on our "Virtual Measurement Campaign" (VMC®) software solution show which drive is suitable for which application.

A parcel delivery service serves roughly the same area every day, braking frequently and starting up again. Perhaps a messenger also leaves the engine running when he brings deliveries to the front door. Employees of craft businesses usually drive to customers' homes where the car is parked for a longer period of time. The target persons are often spread over a larger area than those of the parcel deliverers; thus, cross-country trips are presumably also part of the of the vehicle's usage profile.


© istockphoto/Marcus Millo

The Best Drive for Every Type of Use

Companies involved in vehicle production want to know at an early stage how to develop their vehicles sustainably and in line with demands of the addressed markets. This applies all the more to alternative drive technologies, for which little experience is yet available. Service providers – craft businesses or parcel services – want to put together an optimal vehicle fleet. In view of increased fuel costs and the prospect of innovative drive systems, such planning is all the more important. When is it worth switching to an electric car? Preferably with a fuel cell? And does the installation of a recuperative brake pay off? This technology, which recovers energy during braking, is already in use in rail vehicles and also plays a role in electric vehicles. However, the regenerative brake costs more than a conventional brake.

These few examples alone illustrate the enormous variety of uses on our roads. Michael Burger's team is also investigating which drive is best suited for which application. "To make sustainable drive concepts viable for the future, they must be analyzed and compared under realistic conditions of use. We develop the methods for this and also supply the adequate technology. A major advantage of our offering is that we combine environmental and usage data with analysis and simulation methods to model realistic scenarios for vehicle engineering and development."

Modeling Based on Many Factors

The researchers incorporate a variety of factors into their modeling: route, vehicle, driving behavior and traffic. The basis here is also our software toolbox "Virtual Measurement Campaign" (VMC®). "Our simulation results help public transport operators or freight companies, for example, to put together the optimum drive mix for their vehicle fleet", Michael Burger emphasizes.

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Radome Application Example: Safety Thanks to Terahertz Technology

Modern vehicles contain highly sensitive instruments that must be protected against radiation. One question is particularly important: What material is used for the protective housing?

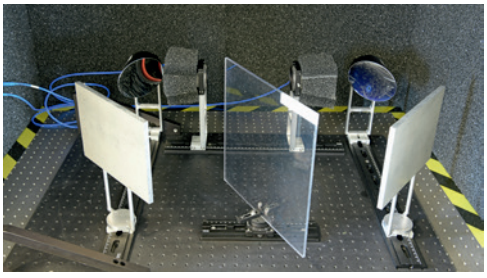
5G works with frequencies up to 40 GHz. The terahertz test uses frequencies from 100 GHz.

Mostly, these are glass fiber composite (GFRP) materials, which are used as multilayer composites. Since GFRPs are permeable to high-frequency radiation, they are used especially where highly sensitive components need to be protected, but the influence of the housing materials on the radiation must remain as low as possible. In the mobility sector in particular, these are mostly classic radar and communication applications, such as distance sensors in automobiles, the 4G and 5G mobile communications standards, and navigation instruments installed in aircraft noses, for example. This is why GRP housings for these applications are also referred to as "radomes".

Testing Radome Multilayer Composites

The Austrian company 4a manufacturing GmbH produces composite materials for radomes (CIMERA radomes), which are used in the 5G mm-wave and satcom industries, among others. Our "Materials Characterization and Testing" department is investigating for the company their composites for high frequency applications, especially in the range between four and 40 GHz. The structure of the complex multilayer composites is crucial here for the functionality of the materials and the question: at which frequencies do the radomes appear as "electromagnetically transparent" as possible for the desired target application? Up to now, 4a manufacturing GmbH has provided results from material simulations that allow statements to be made about this frequency behavior. These simulations are now additionally backed up by high-frequency measurements.

"Thanks to our shielded measurement chamber, we were able to get into the game here," says project manager Dr. Maris Bauer. Transmission and reflection measurements on test radomes verify the simulation results. End customers thus have the additional assurance that the materials from 4a manufacturing GmbH are suitable for their application purposes. In addition, our terahertz testing systems allow us to examine the internal structure of finished radomes, for example, in order to detect possible cracks or similar production defects at an early stage.



www.itwm.fraunhofer.de/terahertz-testing

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Clear the Way for the Modular Inspection Platform

For years, our "Image Processing" department has been working on hot axle box detection on railroad tracks. The aim is to detect hot axle bearings and stationary brakes on passenger and freight trains so that they can be stopped, before serious problems occur.

Sensors in the track bed determine the heat radiation of passing trains without contact and calculate the temperatures from this. If they are outside the standard range, the next control center is automatically informed; typical alarm limits for axle bearings are 100 degrees, for brakes over 300 degrees depending on the type.

Universal Platform for Web Inspection

The requirements in terms of safety and reliability have increased over time: Not only the sensors should work flawlessly, the entire system must work trouble-free and be protected against manipulation from the outside. "For our partner, we are developing an overall system that goes far beyond pure temperature measurement," says project manager Thomas Redenbach, describing the collaboration with Progress Rail Inspection and Information Systems in Mannheim. "We are implementing the system as a modular platform: the individual components communicate in encrypted form via secure communication protocols. Users authenticate themselves in a multi-stage login process to protect the platform as well as possible against hacker attacks." In addition, subsystems can be redundant, which provides increased fail-safety.

The sensor technology is flexible: as required, modules can be retrofitted to detect protruding loads on freight trains, flat spots on wheels or dragging components on the track.

Fault detection during drive-by: Acoustic sensor detects wear condition of axle bearings.

New are acoustic sensors that can detect incipient bearing damage from the noise of a passing train.

Sensor Fusion Enables Predictive Maintenance

The universal platform can combine measured values from different sensors: For example, temperature and acoustic data can be used to determine the wear condition of axle bearings. It is also possible to network several locations in order to track trains over time. This data can be used to detect impending component failures at an early stage and to adapt maintenance cycles to actual wear. The system will go into test operation this year.

www.itwm.fraunhofer.de/signal_analysis_railway

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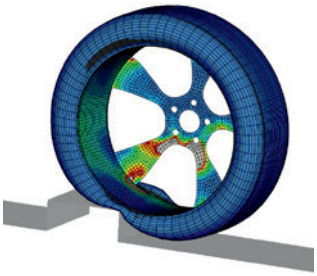
Diverse Mobility Projects at The Fraunhofer ITWM

Electromobility, water management, filter materials – we at Fraunhofer ITWM are researching many facets of "mobility". At this point, we have compiled some projects into which we give short insights.

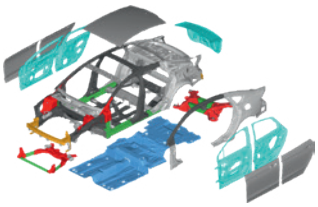
"CDTire": Realistic Simulation of Tires



CDTire is a tire model family for passenger car, truck and agricultural tires, that supports engineers from vehicle and tire manufacturers in almost all simulation scenarios in modern vehicle development processes. Special focus on tire dynamics and interaction with 3D-road surfaces accurately captures the vibrations in both amplitude and frequency behavior with additional capabilities in static and stationary tire behavior. Access to constructional as well as material also allows for quick what-if studies.

www.itwm.fraunhofer.de/cdtire_en

ALMA: Lightweight Construction and Ecological Design for Electric Vehicles

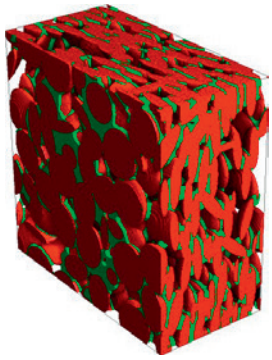


© ALMA

E-mobility and lightweight construction are two building blocks of modern vehicle development to drive the energy transition. The ALMA project is focusing on them. Nine European organizations are working to develop more energy-efficient and sustainable vehicles. Companies from research and industry are optimizing the range of electric vehicles by, among other things, reducing the weight of the overall vehicle. Our team supports with mathematical simulation expertise. See more in the video online.

www.itwm.fraunhofer.de/alma_en

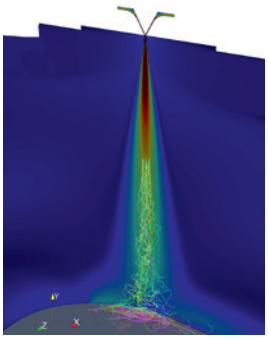
Battery cells for e-mobility



Develop battery cells virtually? The simulation software BEST (Battery and Electrochemistry Simulation Tool) developed at our institute is currently used by experts in the automotive industry for the development of lithium-ion battery cells. In the ABBA-VEEB project, a much more broadly applicable design platform is being created based on BEST – both for the virtual design and for the virtual testing of current high-performance batteries for the e-mobility of tomorrow.

www.itwm.fraunhofer.de/abba_veeb_en

Check Filter Nonwovens Virtually



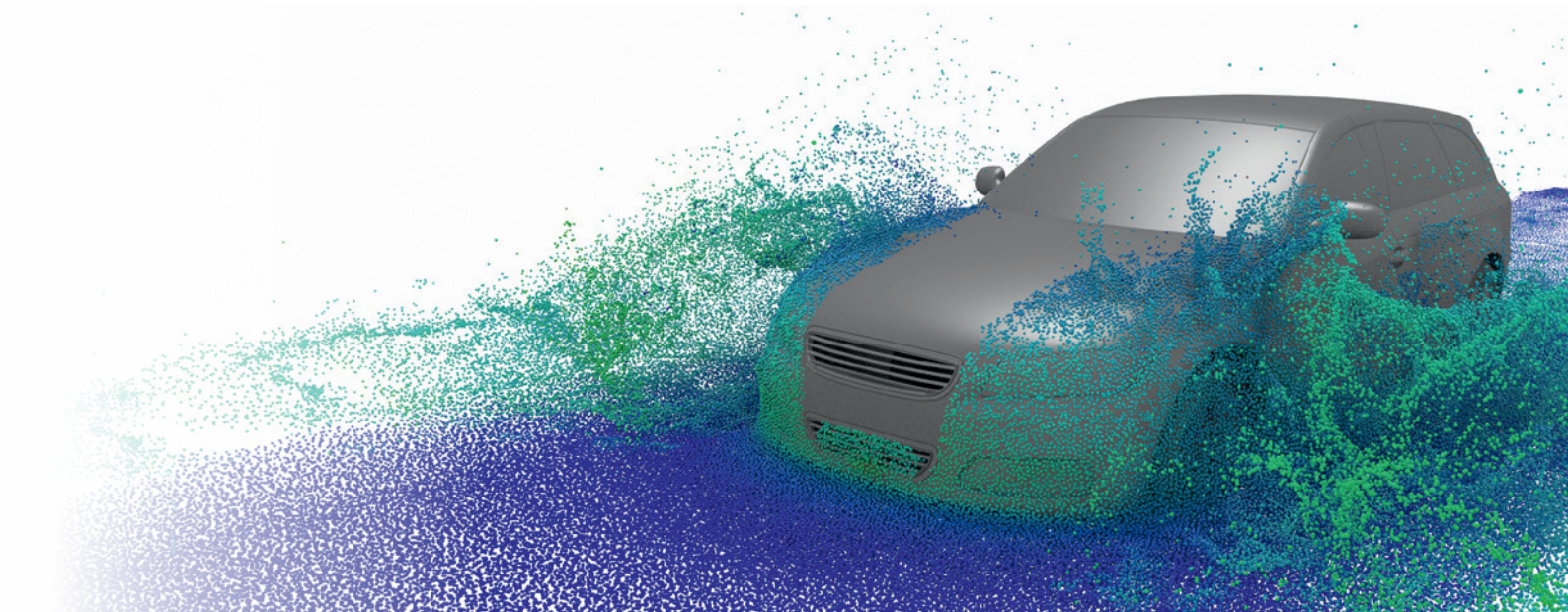
Filters, such as those installed in cars, have to meet increasingly stringent requirements. At the same time, the products should be ready for the market more quickly. Simulations support the developers in this balancing act. In the research project "ProQuIV", an interdepartmental team of the Fraunhofer ITWM has optimized the entire production chain of nonwovens. The findings also benefit the automotive industry in the further development of cabin and pollen filters.

www.itwm.fraunhofer.de/ proquiv-en

MESHFREE: Application Example Water Management

With MESHFREE, we have been providing an innovative software product for grid-free simulation of physical processes in cooperation with Fraunhofer SCAI since 2018, combining the expertise of both institutes in the field of grid-free scientific computing. MESHFREE is based on a general material model that is also suitable for use in water simulations: driving through puddles, rain on the windshield - the automotive company PORSCHE uses MESHFREE for its water management. Find out more on our websites and in the corresponding video!

www.itwm.fraunhofer.de/meshfree_en



European Data Cloud for the Mobility of the Future

The "GAIA-X 4KI" project, part of the European "GAIA-X" project, offers a glimpse into the future. A consortium of industry and research with 16 partners is developing concrete services for the automotive industry in the European computing cloud with the help of artificial intelligence (AI). The aim is to make connected and automated driving safer.

Huge amounts of data are generated when planning, building and operating vehicles. The team in GAIA-X 4 AI uses AI methods to utilize this data efficiently and securely. To do this, our researchers from "High Performance Computing" bring together data and infrastructure, hardware and software. To achieve this, they use "containers" in which they pack the applications and move them between the respective environments like in a marshalling yard. The challenge: to get the containers on the track in such a way that the available computing resources are used optimally. This results in complex mathematical optimization tasks that can only be solved efficiently by considering the entire system of hardware, software and application algorithms. In addition, the users should be able to use their containers not only on their own premises, but also on a platform that is accessible to everyone, without any major effort.

Test Track for Mobility of Tomorrow

In the GAIA-X 4 KI project, the Offenburg University of Applied Sciences, the German Aerospace Center (DLR), and the ITWM team are each building a demonstrator. According to project leader Dr. Dominik Straßel, their special feature is: "Normally, data is uploaded to a cloud and processed there; but downloading the result is expensive. That's why we're taking a different approach: We calculate directly where the data is, i.e. at the project partners' locations. This not only saves money, but also energy." The researchers are focusing on use cases from the automotive industry, aiming to bring automated and connected driving into practice. The German Federal Ministry of Economics and Climate Protection (BMWK) is supporting the project financially.

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"I wish us to be reliable and environmentally friendly on the road!"

Prof. Dr. Anita Schöbel
AI Pilot for Mobility

AI pilot Prof. Dr. Anita Schöbel in her lecture on the topic "Sustainable computing today and in the future" at the Science Notes in April 2022

Three Questions For…

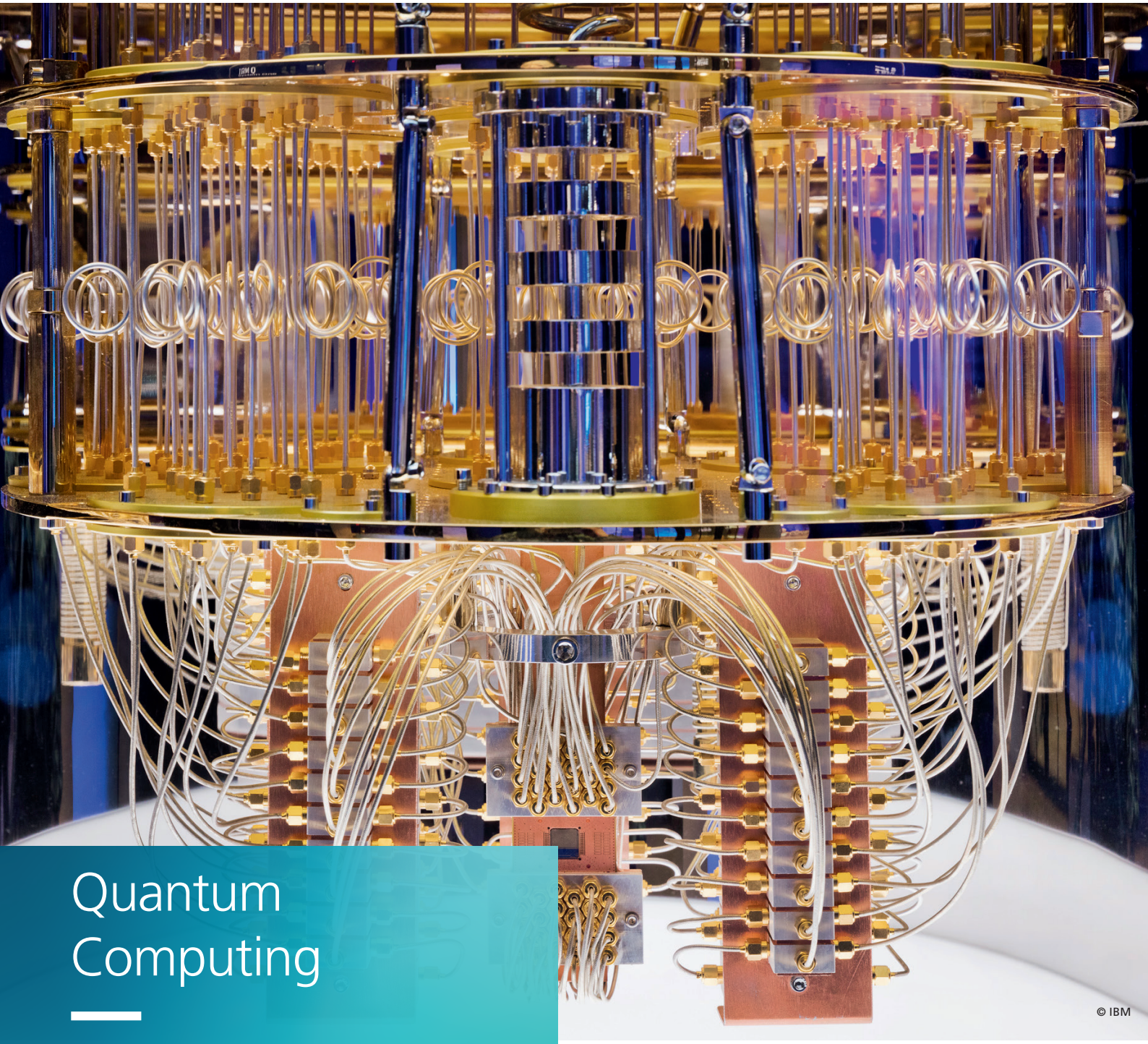
Intelligent systems and networked processes: With the help of AI and machine learning, we are shaping the traffic and vehicle development of tomorrow – sustainably, efficiently and safely. As the AI Pilot for Mobility of the state of Rhineland-Palatinate, our institute director Prof. Dr. Anita Schöbel, together with her advisor Dr. Henrike Stephani, disseminates the knowledge needed for the application of artificial intelligence in the mobility industry.

1 What is particularly important to you about mobility?
The connection of the individual sectors, i.e. that the various modes of transport such as car, bus and train, walking, bicycle or even scooter are considered together and jointly designed to meet demand

2 What are your main areas of research?
In research, I myself am primarily concerned with the optimization of public transport. Typical questions here are: Which lines should be set up? How do you get a good timetable? What structure should the fare system have? How do you react in the event of delays?

3 What do you wish for mobility in the future?
I wish for us to be efficient, reliable and environmentally friendly on the road in the future!

www.itwm.fraunhofer.de/ki_lotsin_en



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Quantum Computing

The Fraunhofer Competence Network Quantum Computing is the first point of contact for anyone who wants to conduct research on and with quantum computing. Regional competence centers in seven German states, each with its own research focus and in turn made up of Fraunhofer institutes, have joined forces in this network. The common goal is to research and develop new technological solutions in the field of quantum computing.

Rhineland-Palatinate Promotes Competence Center for Quantum Computing

The Competence Center Quantum Computing at the Fraunhofer ITWM has already been 2020 from the baptism. It is one of meanwhile eight centers which together form the Fraunhofer Competence Network Quantum Computing. Its expansion is supported by the state of Rhineland-Palatinate with further funding. Clemens Hoch presented the director of the institute, Prof. Dr. Anita Schöbel, with a notice of funding in the amount of 1.2 million euros.

Prof. Dr. Anita Schöbel, Director of the Fraunhofer ITWM, and Minister of Science Clemens Hoch. In the background, the quantum computer System One from IBM, which is being operated by Fraunhofer near Stuttgart.

Prof. Dr. Anita Schöbel is working with Prof. Dr. Manfred Hauswirth (Director at the Fraunhofer Institute for Open Communication Systems FOKUS) responsible for the topic "Quantum Computing" within the Fraunhofer-Gesellschaft. Central research questions are, for example: Which application scenarios are suitable for computation with a quantum computer? How can algorithms be developed for this and translated into applications?

The focus of the competence center is quantum HPC (High Performance Computing). Compared to classical computing, quantum computing promises both an acceleration of certain algorithms as well as and the possibility to compute extremely complex problems in the first place.

Future Technology With Potential

The "Quantum High Performance Computing" competence center now brings together numerous projects with a wide variety of from quantum chemistry to financial mathematics, projects with financial mathematics, projects with an energy focus or material simulation to quantum image processing or quantum machine learning. The overriding goal of the diverse activities is always: the development of quantum-based computing strategies for industrial applications.

Minister of Science Clemens Hoch Hands Over Funding Notification

"You have made good use of the start-up funding," emphasized Science Minister Hoch at the handover ceremony. In the second funding phase, the researchers will deepen the work packages. This includes identifying further applications – a strategy also endorsed by the Industrial Advisory Board. It consists of representatives of BASF, Debeka, Deutsche Bahn and Schaeffler. The state of Rhineland-Palatinate will continue to support the expansion of the center of excellence in quantum computing in the future: Up to five million euros will be made available over the next three years, so that quantum computing can be used to solve problems of social, scientific and economically relevant problems supported.

www.itwm.fraunhofer.de/quantum-technology-professional-en

QCStack: Between Classical Clusters and Quantum Computing

Quantum computing is still a big promise, but at the latest since the first quantum computer went into operation in Germany in June 2021, the future technology has moved a bit into the present. Dr. Valeria Bartsch heads the "Next Generation Computing – Quantum Computing" team and talks in this interview about the current state of research.

What is the state of research In Quantum Computing?

Compared to classical computing, quantum computing is still at the beginning of its development. In principle, we are at the same stage as the first classical computers in the 1950s. We lack an invention similar to that of the transistor, which revolutionized computers and provided a hardware platform on which all further developments are based. We put a lot of work into research and testing. Therefore, we expect a rapid improvement of the hardware, the algorithms and the software stack to deliver on the promise of quantum computing. We want German industry to be ready as soon as the benefits of quantum computing can be implemented in reality. Coming from high-performance computing, we are looking in particular at the software

stack and the integration between classical clusters and quantum computers. We are building an abstraction layer-an interface between the hardware and the application-that every quantum computer needs. As yet, this interface must be implemented individually for each quantum technology and variant. We would like to generalize this step. We are financially supported by the German Federal Ministry of Education and Research (BMBF). The ministry has set up a special funding program for quantum technology. We are leading the project QCStack project and, together with our partners build a suitable middleware.

What does that mean exactly?

The middleware ensures the exchange of data between application programs that work under different operating systems or in heterogeneous networks. In our case these are software stacks, i.e. software packages that build on each other software packages with the task of supporting the execution of a common application. To understand this, it is helpful to compare with an orchestra: The instruments must be tuned, i.e. calibrated, in order for the interaction to work. The music is arranged according to the composition of the orchestra. Likewise, the algorithms are calibrated to run on a particular quantum system. In the orchestra, the conductor gives the instruments the cue, the qubits get their "go" from a scheduler.

This sounds like a big task. Is the Fraunhofer ITWM working alone on QCStack?

The project is a joint effort – we focus on the compiler that translates quantum algorithms to real quantum systems. The "Dahlem Center for Complex Quantum Systems" at Freie Universität Berlin is developing methods for the optimal control of quantum systems and working on their application. Qruise GmbH, a spin-off of Forschungszentrum Jülich, then deals with the commissioning of the software and (re)calibration. At the end of the project – probably in January 2025 – we want to present the first functional iteration of the software; both the core software and the algorithms it contains must then have achieved MVP (Minimal Viable Product) status. This means that our product must be so good that it is of interesting for companies.

Qubits are the smallest computing units in quantum computing.

Fraunhofer operates "IBM Quantum System One"

Since June 2021 quantum computing is possible in Europe: Together with IBM Fraunhofer operates the quantum computer "IBM Quantum System One" under EU data protection guidelines. It is available to companies and research organizations to develop and test application-related quantum algorithms and build up know-how.

www.itwm.fraunhofer.de/QCStack_en

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Quantum Leaps in Science and Career

Dr. Jonas Koppe is research coordinator on the topic of "Quantum Computing" in the the department of "Financial Mathematics". With a team of seven, he is working the most diverse projects of the new technology in this position. What this means in practice and for him as a person, he reveals in the portrait.

Since September 2021 Jonas Koppe has been a staff member at the institute and since February 2022 he occupies the new position of the research coordinator "Quantum Computing" (QC). He moved to the Palatinate specifically because his career has so far taken place in Münsterland: He completed his bachelor's degree and then his master's degree in chemistry at the Westphalian Wilhelms University in Münster, where he then earned his doctorate at the Institute of Physical Chemistry. At the same time, his focus was on a completely different field: new methods for investigate solids using nuclear magnetic resonance spectroscopy. In addition to his chemistry studies, Koppe also earned a bachelor's degree in business administration.

A wide-ranging academic combination, in other words that led him to the institute. "I would describe myself as a physicist rather than a chemist," notes Koppe. And now financial mathematics? How does that fit together? Very well, because the research focus on quantum computing is a mixture of physics, computer science and mathematics, as so is the position as research coordinator.

Coordinator Quantum Computing at the Pulse of Research

"In our department, the main task in the position of research coordinator is to create scientific foundations. I observe ongoing research from an application perspective," says Koppe. "That means a lot of reading, writing, coordinating and making sure that we as experts are visible in the research community and on the pulse of the times. We want to be prepared for current developments, but also to play an active role in shaping state-of-the-art research."

To this end, a number of QC projects are already underway, mainly with purely public funding. Abbreviations such as EniQmA, QuSAA, AnQuC or EnerQuant give the research projects names and direction. EnerQuant, for example, has set itself the goal of exploring the potential of new computing technologies for the energy industry. QuSAA focuses on asset allocation and aims to make the most efficient use of the available hardware. Investment strategies for asset allocation aim at diversifying a portfolio using different asset classes such as bonds, shares or real estate – familiar terrain for the department.

Diversity of Projects and Networking

"In the projects, we as a team can usually build on our expertise in financial mathematics. It forms the basis and the technical work is similar. The new technology is the real challenge." Then it is a matter of analyze together how much potential quantum computing really has – in direct comparison with classical hardware and approaches. Some of the companies involved in the translation into the quantum world are companies with which the department is already working on other projects, such as the R+V Insurance.

In the daily work is not only a close networking with the other ITWM departments important, but also with other Fraunhofer institutes. The heart of the network is the "IBM Quantum System One" in Ehningen near Stuttgart, on which Fraunhofer exclusively calculates.

Quantum computing has a Hype problem

Despite all the quantum computing activity, Koppe cautions, "The topic has a classic hype problem right now: Interest and reporting are enormous. But we're at a point where we can't make any promises yet. There will certainly be successful applications, but we are still in our infancy. There will probably be disillusionment before the applications offer a real quantum advantage," says the 33-year-old.

"Our shared understanding of the practicalities, but also the limitations, of the new technology are just beginning to emerge." Nevertheless, Koppe is optimistic and expects the team to produce competitive products that support companies as early as 2023.

The young technology is facing an exciting turning point, just like the young researcher himself. "The subject matter has little to do with my previous specialized knowledge. But that's why I like being in research." And Koppe is not only discovering new things in science, but also in his new life in Kaiserslautern: "I was surprised to discover how beautiful it is here in the Palatinate Forest and the surrounding. I also played the saxophone in a Big Band for a long time and I'm thinking about starting again." Smaller (quantum) leaps will hopefully soon to be found in all areas of the researcher.

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Changing the World with Research Results

A scientist sits in his quiet chamber and does research ... and then? In the interview, Dr. Jens Krüger talks about how research findings find their way into companies and from there into people's everyday lives. He is Fraunhofer expert for the strategic research field of "Next Generation Computing". This stands on three pillars: the first pillar is based on classical architectures. The second pillar is neuromorphic computers, which function in much the same way as our brain, and the third pillar is quantum computers.

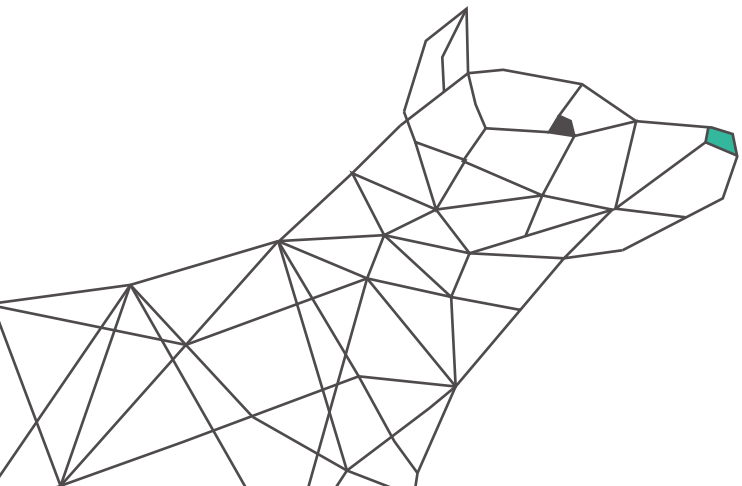
Please briefly summarize what drives you as a researcher?

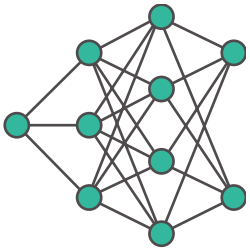
I am a curious person. I want to try out new ideas and develop them further into products that will then benefit our society and the economy. This goes from the development of highly efficient processors to the optimization of artificial neural networks for mobile devices. One example are smart watches that record your ECG. In this way, the device can detect an approaching heart attack and trigger the alarm at an early stage. This technology has the potential to save people's lives.

National science competitions often give research impulses. In March 2021, your team won a prize in the pilot innovation competition "Energy-efficient AI systems" of the Federal Ministry of Education and Research (BMBF). What was that about?

The task was to develop the most energy-efficient AI hardware possible that detects cardiac arrhythmias and atrial fibrillation in ECG data with at least 90 percent accuracy. We entered the competition with was called HALF, which stands for "Holistic AutoML for FPGAs". Our approach was to have an holistic automated machine learning (AutoML) optimization of the neural network model and the FPGA implementation. We investigated the interdependence of the energy consumption of the hardware and the neural network topology.

The choice of network has a considerable influence on the hardware complexity – and thus on the required energy and vice versa. We have optimized these dependencies and developed a new methodology that finds not only more energy efficient models, but also reduces the development time for optimal neural network topologies.



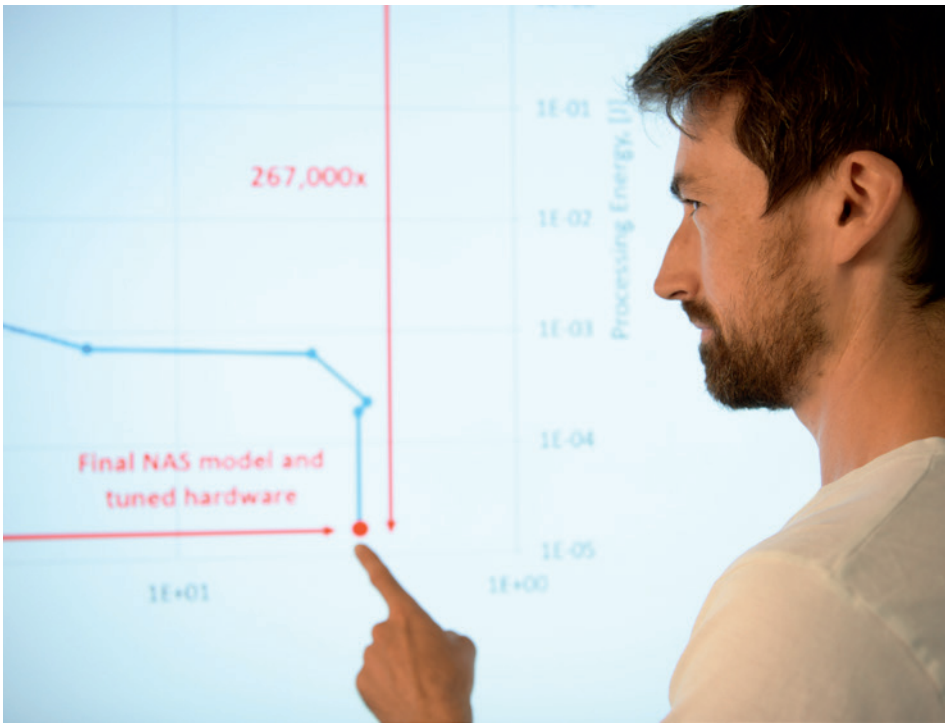


NASE – Neural Architecture Search Engine

What happened after you won the competition?

We now make our expertise available to companies so that they can develop their products accordingly. The AI chip in the competition was merely a test platform. In the follow-up project, we are now working directly with a manufacturer to develop the next generation of devices, which will then be used in clinical trials.

However, we can support all industries, because almost everyone faces the challenge that data volumes are constantly increasing and AI can help to process them. This is economically interesting for almost everyone, for example, for the automotive industry or the telecommunications industry. This gave rise to the software product »NASE« (Neural Architecture Search Engine).



NASE makes scientific expertise available to companies. How does this work?

Every job is individual, but one thing is clear: for us, efficiency starts with the algorithm. We use state-of-the-art methods of automatic neural network search to develop networks that can be efficient with respect to many aspects at the same time. We consider peculiarities of the underlying platform and incorporate them into the network design. The algorithm then adapts the networks to the hardware. For example we can provide our experience, the technology, and computing capacity. Companies provide us with the data sets that are relevant to them and define the requirements, such as accuracy and speed. We then use our supercomputers and our framework to find the best model. The network is then ready for immediate use.

To meet the demand for ever more and faster computing power your team is part of the European Processor Initiative (EPI) which develops highly efficient processors for Europe. What contribution does the Fraunhofer ITWM here?

Our contribution is the so-called Stencil and Tensor Accelerator (STX), which we are developing together with Fraunhofer IIS based on an architecture from ETH Zürich. We focus on the efficient execution of highly parallelizable applications with specific access patterns, as they occur in many applications – from fluid dynamics, climate and weather prediction to imaging techniques. Real-world applications are expected to become more energy efficient, easier to program, and lower cost. Interested parties can already test their own codes on our simulator. Next year, the next generation of test chips will be available. By 2025, we want to have the first complete system up and running. A major challenge, but also an important step toward a new national and European industry for high-performance processors and accelerators.

www.itwm.fraunhofer.de/NASE_EN

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Health and Medicine

Improving health care, increasing the chances of healing, supporting diagnoses – these are the goals that the Fraunhofer-Gesellschaft wants to achieve with results in medical, environmental and nutrition research. Intelligent, assistive systems that support preventive health care, diagnostics, therapy and nursing are intended to help in this. We are focusing in particular on tools for decision support in therapy planning and for strengthening resilience, but also for political decision-making in order to contain the Corona pandemic.

Increasing Chances of Survival through Mathematics

It is a Fraunhofer ITWM success story that has improved the lives of many people: thanks to the planning techniques for radiotherapy developed here, the survival chances of people suffering from cancer have increased significantly. These planning techniques were implemented by Varian Medical Systems, the world's largest manufacturer of radiotherapy equipment, which has been part of Siemens Healthineers since 2021. The collaboration is ongoing.

© TrueBeam® image courtesy of Varian Medical Systems

Radiation therapy is about a trade-off between treatment of the tumor and the risk of side effects. Market leader Varian Medical Solutions relies on software solutions from Fraunhofer ITWM.

The decision support components are used in planning tasks in many different applications in industry. The goal when used in radiotherapy is to reach a sufficiently high dose to the tumor while minimizing the negative impact on surrounding healthy tissue. In this way, severe side effects are avoided in treatments every day in many hospitals around the world, while at the same time increasing the likelihood of successful treatment.

Time as a Decisive Factor in Treatment

Improving planning efficiency as well as higher quality of treatment were the aspirations for the multi-criteria radiotherapy planning tool developed in the Optimization division from the beginning of the collaboration. "For many patients, the time factor is crucial to the success of treatment. We have given treating physicians the opportunity to create very good and personalized therapy plans without having to use a time-consuming trial-and-error procedure," says Dr. Philipp Süss, deputy department head "Optimization – Technical Processes."

Collaboration Continues

Palo Alto-based Varian Medical Solutions is the market leader for radiation oncology equipment. In 2016, the cooperation with Fraunhofer ITWM started; the joint product has been on the market since 2017 and has since been offered in more than 150 countries. Now the collaboration has been extended for another five years. "We are all proud of what we have already achieved together with one of the most successful global players in medical technology and look forward to continuing our joint work to further improve radiotherapy," said Süss.

www.itwm.fraunhofer.de/radiation-therapy

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Software-Optimized Production Processes at BioNTech

Since the Mainz-based company developed the first broadly approved vaccine against COVID-19, the name BioNTech has been widely known. The real concern of BioNTech SE is the development of individualized therapy for cancer patients. For both use cases – the production of the individualized cancer drugs as well as the Corona vaccine – researchers of the Fraunhofer ITWM have developed a software platform, with which the production process can be controlled more effectively.

The production of individualized drugs is complex from both a technical and organizational perspective and differs fundamentally from established processes in the pharmaceutical industry. Individualization raises a variety of novel issues and requires new approaches to production organization and planning. For example, all steps must be carried out individually for each patient. For many years, this was not the focus of established solutions for production planning.

Customized Solution

To develop a platform that plans and coordinates these processes is the task of the team around Dr. Heiner Ackermann, head of the department "Optimization – Operations Research". First, the previous knowledge of the scientists at BioNTech had to be combined with that of the ITWM researchers. "Finding a common language, a common understanding of processes, was an essential part of our work," says Ackermann. Modeling, structuring, and analyzing data and processes followed. The end result was software that could be used to plan and organize the manufacturing processes of the individual drugs, and which provides a completion forecast for the respective patients.

The researchers at Fraunhofer ITWM continuously adapt the software to the changing requirements of vaccine production.

Automated Processes for Increasing Production Figures

Several of BioNTech's oncology product candidates are already in advanced stages of development and will soon enter pivotal trials. Production for commercial distribution is already being prepared today. This also has an impact on the planning processes: They sometimes need to be adapted and expanded, particularly with regard to greater automation. Preparations for this are already underway. "With a few hundred patients, manual intervention in the process is still possible. This will no longer be possible with several 10000. Automated processes and additional decision support options may be required there," says Ackermann, describing the advantages of an automated planning process.

Whether cancer therapy or vaccine production – the Fraunhofer ITWM and BioNTech develop software to improve the planning, coordination, and documentation of complex production processes.

And Then Came Corona

With the onset of the Corona pandemic, BioNTech is also using its expertise on mRNA-based anticancer drugs to develop a vaccine. "I learned from a newspaper article that BioNTech was planning to develop a vaccine. Shortly thereafter, the company inquired about working with us on new software solutions. That's when chaos briefly broke out for me, but of course we got to work," Ackermann looks back.

The manufacturing process for the vaccine is much less complex than that for the individual cancer drugs. The critical issue here is production capacity for the hundreds of millions of vaccine doses required. The solution is for BioNTech to work with contract manufacturers who specialize in certain process steps.

The Fraunhofer ITWM and BioNTech have established software that allows the company to plan, coordinate, and document the production network and the individual process steps. "Now we are working on adapting the platform to the ever-changing requirements. As the production process evolves, we are also developing the platform. In some cases requirements change on a weekly basis, but this is a challenge that we're coping very well with," says Ackermann, describing the ongoing collaboration.

www.leistungszentrum-simulation-software.de/processes_biontech

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Corona Pandemic: Fraunhofer ITWM Advises State Government of Rhineland-Palatinate

During the Corona pandemic, the weekly forecasts for the expected infection numbers by Fraunhofer ITWM are important indicators for the state government of Rhineland-Palatinate to make political decisions. Our researchers have contributed to the fact that the state has weathered the pandemic better than other German states.

"The forecast for the coming days" – a phrase you're actually more familiar with from weather reports, but not in connection with hospital loads, intensive care bed occupancies and mortality rates. In the Corona pandemic, the forecast of the number of infections is a crucial factor in deciding whether to tighten or loosen protective measures.

Provide decision makers with solid foundations

In April 2020, Fraunhofer ITWM began making forecasts of pandemic developments. Initially, in order to better prepare hospitals, municipalities, and public health departments for what was to come. "It was clear to us: we can calculate what's coming. Then we asked the district councils and mayors in Rhineland-Palatinate whether they needed help. For the political players, our calculations were authoritative decision-making criteria."

Behind the forecasts is a dedicated team that brings together diverse expertise and experience across departments to jointly contribute to pandemic response. The accuracy of the predictions is remarkable. The Rhineland-Palatinate state government is also aware of this fact, so that a weekly meeting has been arranged with representatives of the Ministry of Science and Health and the State Investigation Office since August 2021. The results received attention by several ministries and by Minister President Malu Dreyer. The cooperation is having an effect: Rhineland-Palatinate is coming through the pandemic relatively unscathed.

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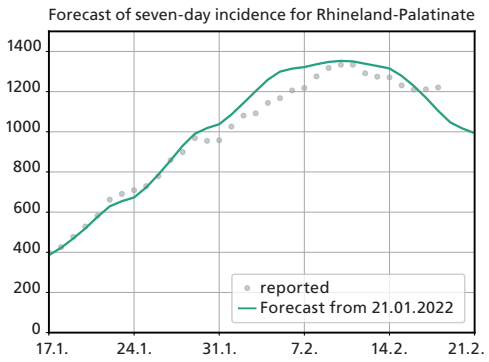
Calculating the Future From the Past

"We have developed a simulation and forecasting program to look into the future based on reported values from the past," says Dr. Jan Mohring from the "Transport Processes" department. What is modeled is how the infection figures develop. Parameters are contact, testing and vaccination rates. The dynamic events are reconstructed on the basis of the numbers recorded over the last few weeks. For this purpose, the contact and detection rates are adjusted so that the model reproduces the reported new infections and deaths for the past. and deaths. The parameters found are then used to extrapolate the spread dynamics into the future. From this, forecasts can finally be made for indices such as mortality rates or intensive care bed occupancy rates.

During the pandemic, the system could be increasingly supplemented and adapted. The accuracy of the hits impressed everyone involved: "We predicted the peak incidence of the fourth wave in February 2022 for Rhineland-Palatinate to the day and the incidence with a deviation of about 20 cases – and that three weeks in advance," says Mohring. This also makes it clear that testing is an important part of the pandemic response. In Mohring's



The maximum of the Omikron-BA.1 wave was predicted three weeks earlier with a deviation of less than two percent.

view, even more crucial than contact restrictions, which is why Fraunhofer ITWM was an early advocate of representative testing in schools as a containment measure. The state was also one of the first to introduce 2G-Plus on the advice of Fraunhofer ITWM.

Mirroring Human Behavior

With relaxations in the summer and the scaling back of regular testing, it became more difficult to provide concrete forecasts. However, since a changing detection rate is explicitly taken into account, forecasts remain at least possible with trade-offs in accuracy. Therefore, the Fraunhofer ITWM continues to work on its modeling software and is starting a new project with the Catastrophe Research Center from Berlin and the German Research Center for Artificial Intelligence (DFKI), in order to be able in the future to incorporate feedback that takes greater account of people's behavior. more closely. "Central to this for us is the question is how knowledge of a threat situation influences people's influences people's behavior," says Mohring.

When Will the Pandemic Be Over?

The question about the end of the pandemic has often been asked to the researchers of Fraunhofer ITWM. There is a consensus: We will not get rid of Corona any time soon. Depending on the prevailing variant of the virus, the summer months will be more summer months will be more relaxed than the cold seasons. Küfer and Mohring agree, however agree: "The fall wave will roll." Measures will depend on the particular variant of the virus. The consulting services of the Fraunhofer ITWM for the state of Rhineland-Palatinate will continue.

www.itwm.fraunhofer.de/itwm-vs-corona

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Digitization

Every day, large volumes of diverse data are generated at high speed all over the world – in companies, urban infrastructures and private households. The volume is growing steadily, and the processing and analysis of these huge volumes of data is becoming a key competence for high-tech countries. We provide advice and support to companies in building up know-how and developing solutions in business processes such as production and logistics. Equally, we emphasize feasibility, cost-effectiveness as well as data protection and security.

T-KOS: Terahertz Technology for Reliable Communication

Taking part in a virtual meeting while traveling by train – no problem if there are no gaps in the mobile network. Mobile working underscores the importance of stable data connections. This applies equally to industrial production, which is relying more and more on networked components. Our "Materials Characterization and Testing" department is researching how terahertz technology can additionally optimize the integration of assemblies through improved sensor technology.

The requirements for communication networks and sensor solutions in industrial production processes are growing, which is why the German Federal Ministry of Education and Research (BMBF) launched the T-KOS project (Terahertz Technologies for Future-Oriented Innovations in Communication and Sensor Technology) in 2021. In the project, terahertz technology is now being developed synergistically for industry in the fields of "communication" and "sensor technology" for the first time.

Working together to achieve compact system concepts

T-KOS is a joint project of "Forschungsfabrik Mikroelektronik Deutschland "and Fraunhofer ITWM. It bundles the commitment of ten cooperation partners. The researchers are developing demonstrators for wireless communication with high bit rates and industrial measurement technology based on high-frequency electronics and terahertz photonics.

One promising way to increase data capacity at carrier frequencies above 100 GHz is terahertz radio technology. The higher the carrier frequency, the greater the usable bandwidth and thus the data capacity. This means that smaller antenna elements are needed and compact radio systems can be realized with a large number of active antennas. This is an advantage that also benefits industrial terahertz measurement technology, which is used for imaging and testing.

Demonstrators for imaging Terahertz testing

"Electronic and photonic system concepts in the terahertz range are conceptually close to each other," says Dr. Fabian Friederich, coordinator of the T-KOS activities at Fraunhofer ITWM. "Thanks to our expertise and our good laboratory equipment, we can realize demonstrators for both branches of technology in Kaiserslautern for imaging terahertz testing in production processes." While the all-electronic demonstrator aims to provide industrial-grade inline measurement technology with millimeter resolution on the production line, the photonic concept serves as a research platform for future developments towards higher frequencies and improved resolution.

www.itwm.fraunhofer.de/terahertz-testing

T-KOS
Terahertz-Technologien für Kommunikation und Sensorik

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Enterprise Lab: Through Modern Working Methods to Mathematical Success

In the cooperative working method "Fraunhofer Enterprise Lab", several experts from companies and ITWM researchers actively work together in a team on topics and solutions. Our department "Financial Mathematics" thus implements innovations in direct collaboration with an automobile manufacturer.

8
Subprojects in three years

In the focus of the "Enterprise Lab", everything goes hand in hand – from topic identification to market-ready solution. The symbiosis of research and corporate practice enables the implementation of creative ideas that are directly aligned with business processes. "With the Enterprise Lab, we have created an agile method in which companies can live interdisciplinary collaboration with us researchers and work collegially with customers", says Dr. Stefanie Schwaar, business unit developer "Accounting Audit." "They don't just order technologies from us in the classical way and we work off them, but we develop the task, strategy and solutions together.

Our success is based on three components.

© iStock/aldorado10

“With the Enterprise Lab, we have created an agile method in which companies can live interdisciplinary collaboration with us researchers and work collegially with customers.”

Dr. Stefanie Schwaar
Business Unit Developer “Accounting Audit”

Example Data Science in the Automotive Industry

One example of the successful implementation of the concept is the collaboration with a premium car manufacturer. “Here, we have already been working on a wide variety of topics since 2018. The team keeps changing, depending on the expertise required,” says Schwaar. In the lab, companies have direct access to the know-how of the scientists. Everything revolves around challenging data sets in the area of testing and forecasting.

Thus, completely new possibilities for explorative data analysis have emerged in the Lab, such as a specific anomaly detection: The Fraunhofer ITWM solution supports the merging of complex data from different sources, aggregates them automatically to an efficiently usable data set, and visualizes them interactively. Statistical and machine learning (ML) methods are used to automatically search for anomalies in the data. In this way, potential incorrect entries or presumably underbilled repairs can be investigated in a targeted manner and major sources of error can be identified at an early stage.

Interdepartmental Project Planning in the Lab

The flexible working model enables strategic cooperation – even across departments. In the lab’s latest project a team from the “Mathematics in Vehicle Development” and the “Financial Mathematics” department is working together on the digital processing of complex vehicle analysis protocols. That means Big Data on a grand scale. The range of topics for using the data is extensive and constantly changing. When a new car goes on the market, there are various questions to be answered such as: What is the predicted damage rate? What are the frequent repairs? What costs can be expected? For these and related questions, we provide data-driven support.

The development of an ML-supported interactive analysis tool is also the focus here. Experts from both departments work closely with the teams from the customers’ teams, and a steering committee ensures the conceptual orientation and goal setting. A real formula for success in modern project work.

www.itwm.fraunhofer.de /datascience-car

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Mathematics Creates Transparency – Making Secure Provision for Old Age

Since 2016, a team from the "Financial Mathematics" department has been carrying out classification for state-subsidized pension products on behalf of "Produktinformationsstelle Altersvorsorge gGmbH (PIA)." A model that has set standards and has now been adapted to make company pension plan contracts objectively comparable.

Old-age provision in Germany is based on three pillars: mandatory systems under public law (including statutory pension insurance), occupational pension schemes and private pension contracts. The latter include products that are subsidized by the state, for example through the so-called Riester pension. In the meantime, the range of products is very complex and it is difficult for consumers to keep an overview. To alleviate uncertainty and create more transparency, the Ministry of Finance introduced a classification for state-subsidized contracts, including, for example, the Riester products. In order to be subsidized, they must comply with legal requirements and be classified.

The basis for this is provided by mathematics from the Fraunhofer ITWM. Since 2017, the PIA has been assigning each state-subsidized pension product a risk-reward classification for the standardized information sheet. Their standard comprises five classes - from one as strongly safety-oriented to five as yield-oriented. As a rule, a rising risk level is linked to increasing opportunities for returns. Interested parties are thus provided with a standardized assessment framework for products, which captures the key characteristics of the policies and allows them to compare rates.

PIA Provides Insight with the Help of Mathematics

For this purpose, the PIA was founded as a non-profit organization. An ITWM team from the department "Financial Mathematics" has been working for the PIA for more than six years and evaluates the insurance tariffs. Both are entrepreneurially separated. The contract simulations for the classification into chance-risk classes are carried out at Fraunhofer ITWM.

"We have already evaluated several thousand contracts and PIA has classified them. The PIA basic model was developed by our institute and is now considered the industry standard," says Dr. Roman Horsky. "In this way, we ensure greater transparency for policyholders. Of course, we cannot predict long-term economic developments, but models simulate different development scenarios based on the current economic situation. This is always changing, which is why the parameters of our simulation model are also readjusted annually," emphasizes the financial mathematician. PIA communicates the risk classification alone and does not provide specific tips or advice on the selection of a product.

"We have already come to appreciate the close cooperation with Fraunhofer ITWM during the establishment of the Pension Improvement Act. With the consortium 'Das Rentenwerk', we have also entered completely new territory."

Dr. Normann Pankratz
Member of the Board of Management Debeka Versicherungen


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Setting Industry Standards Also for Company Pension Plans

This basic model has become established in recent years. At the European level, a market model that is recognized in the industry is needed. The German Actuarial Association (DAV) recommends the use of the PIA basic model, and other countries have already adopted this proposal in an adapted form.

An adapted model for comparing rates could also support insured persons in the area of "company pension plans". This pillar of old-age provision includes further different tariffs and the offers include different model calculations as well as performance indicators. It is difficult for interested parties to evaluate the products. Therefore the ITWM team is now working together with Debeka on a project for more transparency. The insurance company has developed a new pension product for the company pension plan to be offered in 2023.

Similar to other pension products the key product figures important for sales are to be determined on the basis of a mathematical model. The goal also here: To create an evaluation framework for tariffs that to create a fair comparison of offers enables. Ideally, a cross-pillar standard should emerge that makes it easier for the insured persons to assess their pension provision their pension provision in a holistic manner.

To read the full interview with Dr. Normann Pankratz, go to:
www.itwm.fraunhofer.de/interview-debeka

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Bauhaus.MobilityLab – AI in the Big City Experiment


© Bauhaus.MobilityLab

With the help of AI, innovative solutions are being developed in the areas of mobility, logistics and energy are being developed and tested under real conditions in the Brühl urban district in Erfurt.

In Erfurt, interdisciplinary innovation becomes reality in the Bauhaus.MobilityLab: A digital laboratory platform and experiments in the living lab contribute to the development of AI-based solutions. Mobility, logistics and energy are being rethought for urban planning. Our institute supports with expertise and AI methods.

The project "Bauhaus.MobilityLab – Innovation by Experiment" develops and realizes sustainable and intelligent solutions in the living lab in Erfurt, more precisely in the Brühl urban district. The experimental ideas workshop is in the spirit of the open Weimar Bauhaus tradition, hence the name. The consortium is made up of a cross-domain association of research institutes, large, small and medium-sized companies as well as universities and the state capital Erfurt.

As part of the project, the researchers are looking at a wide variety of challenges in urban space. In cooperation with the TU Kaiserslautern, the ITWM researchers are modeling problems mathematically and developing new approaches to solutions that make use of both AI and data science. This means new optimization potential in urban life in many places.

Testing New Innovations With AI and Mathematics

"Our team is involved in various work packages in the Lab – of course, mathematics and algorithms are everywhere," says Stefanie Grimm, responsible for the project at the Fraunhofer ITWM. "Our main task: we lead the work package 'AI methods' and thus develop the machine learning core of the platform. In application practice this also means that we provide concrete support with prediction methods. A current use case is the prediction of nitrogen dioxide levels, which say a lot about the city's air quality." Another example is the combined route planning for delivery trucks and cargo bikes in the last mile of parcel delivery. As a result, there mathematical optimization means lower traffic congestion and higher environmental friendliness.

But the prediction of parking space utilization also supports urban planning in the real lab. "Our results contribute to the development of a livable city center. Currently, we are also working in the consortium on a Bauhaus.MobilityLab app, which will facilitate participation in our in our experiment more easily," says Grimm. Another major component of the project is "federated learning", a new type of machine learning method. machine learning method. Here all training data is stored exclusively on local devices or clients, and model training is training is decentralized.

Data Science for the Smart City of the Future

To date, the applications have been developed and deployed on a cloud platform, which brings together data from different areas such as transport, logistics and energy. The project will run for three years and is funded by the German Federal Ministry for Economic Affairs and Climate Protection BMWK.

www.itwm.fraunhofer.de/bauhausmobilitylab_en

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Artificial Intelligence Detects Illegally Imported Wood

Together with the Thünen Center of Competence for Timber Harvesting in Hamburg, we support customs authorities in detecting illegally imported timber. This is made possible by our AI-based analysis software, which we design and further develop in the "Image Processing" department.

Anyone importing a wood product into the EU must prove with a certificate that the wood does not come from illegal logging. In addition, customs authorities randomly inspect imported furniture and veneers as well as paper and fiberboard. The Thünen Institute for Wood Research in Hamburg often serves as the analysis expert for industry and authorities. „These checks have already led to a number of fine guitars being confiscated prior to an international music fair because their bodies were made of illegally harvested woods," describes project manager Dr. Henrike Stephani the effectiveness of the authorities.

From Mush to Tree

Especially for papers and fiberboards, not whole pieces of wood are examined, but their macerate. This is understood to be a pulp of crushed wood chips from which certain ingredients are dissolved out with water or alcohol. The pulp is treated with various color solutions and applied to glass in a film only a few micrometers thick. This macerate film is so thin that individual vessels can be identified and classified. Up to now, employees of the Thünen Institute have done this by hand and visually. This procedure is time-consuming and sometimes error-prone, which is why the control is to be automated.

"This is where our algorithms come into play," explains Stephani. Using reference specimen that the Thünen Institute produces from its huge wood inventory and makes available as high-resolution microscope images, the researchers train neural networks. Ultimately, the goal is to succeed in uniquely identifying wood. "At the moment, we are only dealing with hardwoods, because here every tree species has unique markers." The goal of the project, however, is a database of all common wood species.

Fiber analysis of a eucalyptus from the Thünen Institute for Wood Research

The Thünen Institute

The Thünen Institute is subordinate to the Federal Ministry of Food and Agriculture (BMEL) and conducts interdisciplinary research aimed at the sustainable development of rural areas, agriculture, forestry and the timber industry, as well as fisheries. It takes socio-economic, ecological and technological aspects into account. As a departmental research institution, the institute develops scientific foundations as a decision-making aid for the federal government's policy. www.thuenen.de

www.itwm.fraunhofer.de/ki-wood-en

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Energy

Our focus is on renewable energies, efficiency technologies, smart grids and the digitization of the energy industry. Small and medium-sized enterprises have access to a wide range of research and development services.Always the focus is always on a secure, sustainable, economical and socially just supply of energy.

Test Phase Started: Charging Structures In Comparison

The Amperix energy management system from the "Green by IT" group of the „High Performance Computing" division enables the efficient use of battery storage systems, heat pumps and charging stations for e-vehicles and optimizes their control. The in-house solution is also in use in the Fraunhofer ITWM building. Currently, the team is testing eight different charging devices for electric cars.

Fill it up, please! The Fraunhofer ITWM tests charging on-site charging systems.

When is the optimal time to charge the e-car? From the driver's point of view, the charging process should be as incidental as possible, during an appointment, working hours, shopping or parked at home. Those who operate a charging station are driven by the question of when the electricity stored in the vehicles is particularly cheap and when it is better not to use too much electricity. The Amperix energy management system, which is suitable for private households as well as for both private households and businesses.

Theory and Practice Combined on Site

In order to optimally further develop the system to meet the requirements of electromobility, eight different wall boxes are in use at Fraunhofer ITWM. "We test different operating and control strategies live at our institute and gain practical experience, which we then incorporate into our Amperix," describes group leader Matthias Klein-Schlößl. "This brings us significantly further overall further, because we combine theory and practice."

Exceeding the Load Peak Is Expensive

Special attention is paid to the topic of "peak load shaving". Load peaks occur in many companies that have significantly higher electricity consumption at certain times. This aspect is very important for businesses, because it can quickly become expensive: Anyone who exceeds their load peak once a year for a quarter of an hour can be charged additional grid usage fees in the five-digit range," explains Klein-Schlößl.

This means that if electric cars are also charged during a peak period of electricity consumption, for example at lunchtime when a company's cafeteria is in full operation, this can quickly and unnoticeably drive up costs. But not if a reliable energy and load management system like Amperix is in place. Grid-serving measures such as avoiding load peaks and keeping consumption as constant and predictable as possible also help to keep the power grid stable and trouble-free.

www.itwm.fraunhofer.de/amperix_en

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District Heating – Mathematics Heats Up

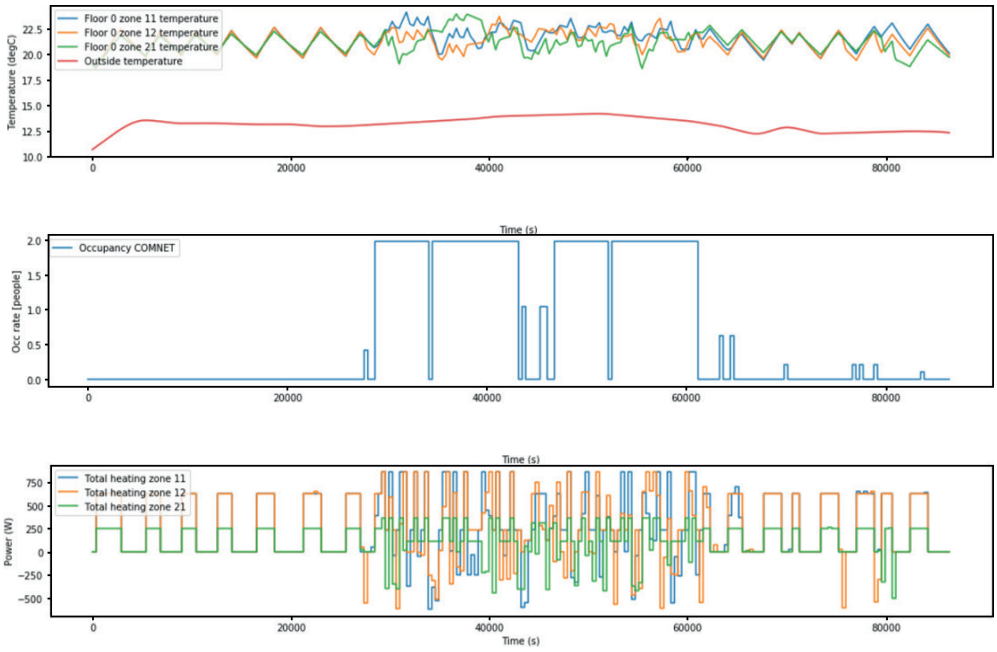
In the "District Heating" project, a team from our "System Analysis, Prognosis and Control" department is working on modeling digital twins of buildings using modern mathematics. Together with the Swedish institute Fraunhofer Chalmers Centre for Industrial Mathematics FCC, the aim is to use simulations to optimize heating with district heating.

73
percent of EU inhabitants live in urban areas.

Currently, heating is a major topic of discussion, especially with regard to the energy transition. In order to be more independent of gas, one hears more and more often that district heating and heat pumps should replace or supplement gas heating. District heating is a centralized heating system. In this system, heat reaches the building via pipelines from a power plant. There is no need for a separate heating system. Centralization allows the use of different energy sources, which are still mostly a mix of natural gas, waste incineration and hard coal. In the future, renewable energies are to be predominant.

District Heating Has Potential

The heating technology is particularly suitable for urban areas and building complexes, because the laying of the networks and the construction of the generation plants pays off when as many people as possible are connected to the district heating network. In 2010, about 73 percent of all 502 million EU inhabitants already lived in urban areas. The potential is therefore great, but district heating still plays a relatively small role. In Germany in particular, not much use is made of the technology compared with the rest of Europe. In Swe-



Simulation results on three levels: Simulated temperature curves of three rooms and outdoor temperature (top), room occupancy in persons (middle), energy gain and loss of the rooms under the district heating consideration (bottom).

den, on the other hand, almost all cities have district heating powered by biomass, and more than 50 percent already run on the central heating solution – and the trend is rising.

European Mathematics Optimized District Heating Technology

No wonder, then, that our Swedish Fraunhofer colleagues are driving research there. In the "District Heating" project, an ITWM team led by Sophie Hertzog has been modeling digital twins of buildings with researchers from Fraunhofer FCC since 2019 in order to optimize district heating technology. "At the beginning, there were very simplified models and we worked, among other things, with Modelica, a modeling language for modeling, simulating, optimizing, and analyzing dynamic systems," the scientist explains. First, various basic properties of the building are included: for example, the size, number of floors, location and orientation, number of windows or building materials. "The digital twin is then supplemented by more complex stochastic input and we consider questions such as: How many people are statistically in this type of building? How do they use the windows for ventilation? Or the blinds for shading? What kind of hot water consumption is there? Which electrical devices radiate heat?" the researcher says.

Currently, a software tool that has been developed is used to forecast heat in buildings in this way. In the future, the focus will then be on energy consumption. In addition, the control of heating systems is also being looked at on the basis of the work. Model predictive controllers (MPC) could then ensure that the amount of energy needed flows depending on the time of day.

www.itwm.fraunhofer.de/5gain_en

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Digitalization and Artificial Intelligence for Energy Management 2.0

Whether as an action to contain the climate crisis, to reduce energy imports or simply to save money: Saving energy is more necessary than ever. With the help of digitization and artificial intelligence (AI), researchers at Fraunhofer ITWM are working on an integrated energy management system that reduces energy consumption and increases the share of renewable energy. Both in industry and in private households.

Energy management 2.0 is the goal of the ENERDIG project. To this end, researchers from the divisions "Optimization" and "High Performance Computing" as well as the departments "Transport Processes" and "System Analysis, Prognosis and Control" are bringing their expertise together to develop new digitization and AI-based strategies. The project is located in the High Performance Center Simulation- and Software-based Innovation.

"The team's research work addresses four topics," explains project leader Dr. Dietmar Hietel. "Energy management in residential buildings and industry, in plastics production, in chemical production and in nonwovens production."

Electricity, Heat and Mobility in Residential Buildings and Industry

An important way to reduce greenhouse gas emissions in the residential and commercial sectors is to use renewable electricity in conjunction with heat pumps and solar thermal energy. "In doing so, people ask themselves, for example, what their consumption will be tomorrow and what their photovoltaic and solar thermal systems will do then. And what role the weather plays in this," said Hietel. "To answer that, we're developing new methods of AI to use forecasts to charge electricity storage systems, which in turn can charge heat pumps and electric cars with as much renewable energy as possible."

Within the framework of ENERDIG, Fraunhofer ITWM is developing new AI methods and procedures to manage the coupling of electricity and heat in buildings and industry on the basis of forecasts.

Ministerial Director Daniel Stich presents Prof. Dr. Anita Schöbel and Dr. Dietmar Hietel with the funding decision for the ENERDIG project amounting to around 1.8 million euros. The funding comes from the European Regional Development Fund.

Optimization of Aerodynamics in the Nonwoven Production

There is also great potential for savings in industrial production, for example in nonwovens production. The challenges in nonwovens production are very high production speeds and turbulence in the production process. Both often lead to fluctuations in fabric quality. With the help of different software solutions, Fraunhofer ITWM contributes to the aerodynamic optimization of nonwoven production. This leads to a more stable product quality and to significant energy savings.

Flexibilization of Energy Use in Plastics Production

High cost pressure and growing complexity in production outline the area of tension in plastics production. By controlling the demand for electricity through the targeted switching off and on of loads, so-called demand-side management, the electricity required for production can be purchased more cheaply on the energy market and the product can be manufactured more cheaply accordingly. In addition to strengthening the market position, the operator of the demand-side management system thus contributes to increasing the share of renewable energies. With the aim to support especially SMEs on their way to an energy management 2.0, Fraunhofer ITWM develops algorithms for the identification and evaluation of energy consumption and flexibility based on digital twins of machines and production facilities. Innovative methods of machine learning (ML) with deep neural networks are used.

Energy Efficiency in Chemical Production Through Real-Time Optimization

A similar solution approach applies in the energy-intensive chemical industry: "Making energy consumption more flexible here means that the company adapts its processes to changing energy costs at short notice," explains Hietel. "In addition, there are other variables that must be reacted to at short notice, such as the availability of raw materials." Systematically taking these fluctuations into account when optimizing plants is one of ENERDIG's goals. "Through improved real-time optimization of chemical processes alone, we can expect energy savings even in the double-digit percentage range."

www.itwm.fraunhofer.de/enerdig-pm [only available in German]

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Microparticles With a Big Impact: Aerosols in Climate Models

Solid particles in our atmosphere play an important role in our climate system and consequently also for climate change. Their inclusion in microphysical climate models is a central challenge in the creation of global long-term forecasts. How machine learning can help here is being investigated in a paper from our "High Performance Computing" department.

The physical forces resulting from the motion and transformation of aerosol masses in the atmosphere are the greatest sources of largest sources of uncertainty in measuring man-made climate effects. Aerosols are produced, for example, by the burning of fossil fuels or volcanic eruptions. Depending on their type, they scatter or absorb atmospheric radiation, depending on their type, and thus cause either cooling or warming effects. So-called "condensation nuclei" also cause an extension of the lifetime of clouds by reflecting sunlight.

The Problem Lies in the Aerosol Detail

The computational detection and consideration of aerosol effects in climate models represents a major challenge for research. These are very marginal, microphysical changes and trends that are extremely time-consuming and costly to calculate. As a result, many models consider aerosols only as constant, external parameters and record them only once in the data collection process. In addition, they often do not distinguish between different aerosol types and simply assume that the particle mass is heterogeneous but one-dimensional with respect to the climate effect.

One of the models, which can model different aerosols is the aerosol microphysics model developed by the Max Planck Institute for Meteorology in Hamburg. Aerosol Microphysics Model. This distinguishes between different aerosol types such as sea salt, sulfates and black carbon. It also captures various physical processes such as nucleation (formation of condensation nuclei), condensation and water absorption.

Machine Learning as the Key to Optimization

Our PhD student Paula Harder from the area of "High Performance Computing" focuses on the topics "Deep Learning" and "Climate Modeling" in cooperation with the University of Oxford. In her research work, she is developing, among other things, an emulator based on artificial intelligence that approximates the microphysics of the aerosol model and makes the calculations faster and more efficient.

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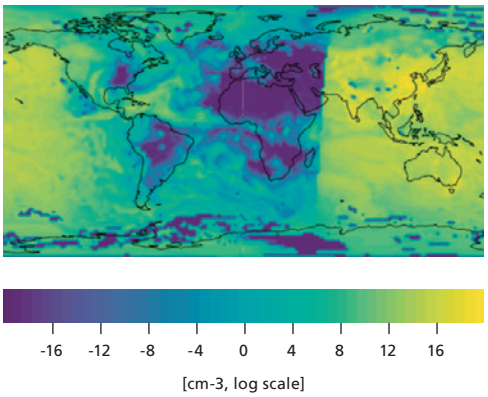
In computer technology, an emulator is a system that emulates another system in certain aspects. Harder explains: "Our goal is to enable climate predictions on a global scale, with very high precision and over long periods of time through machine learning. Herein lies an opportunity to, if not prevent, at least detect and prepare for the consequences of climate change."

To accomplish this, 11 million input-output data pairs were first generated using the aerosol model. This data was then used to train a neural network to replace the costly origin model. Subsequently, additional computational constraints were incorporated to overcome physical constraints – such as conservation of mass and positivity – were taken into account.



The plot shows the predicted change in concentration of aerosols on a logarithmic scale.

A Promising Perspective

The results are extremely satisfactory: The replication of the aerosol model by the neural network works very well in the offline experiments so far – in fact, a higher precision is achieved. Finally, on a GPU, the computation time was recently accelerated to 64 times the value of the original model. By this procedure the emulator can be embedded again into an online global climate model, this is the next step.

The central problem of today's climate research – i.e., the short-term, cost-effective capture and calculation of aerosol masses – is thus expected to be overcome in the near future.

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Plant and Mechanical Engineering

Germany and in Worldwide, plant and mechanical engineering are facing a major test: in addition to solutions for CO2-neutral and digital technologies, resilient value creation structures must also be developed and deployed. We are meeting these challenges and contributing our technological expertise, for example by simulating plants or creating digital twins.

Healing Pigments Against Corrosion

Corrosion shortens the service life of metallic surfaces on aircraft and automobiles. The VIPCOAT project (Virtual Open Innovation Platform for Active Protective Coatings Guided by Modeling and Optimization), which is funded by the European Union, is looking for new solutions for corrosion protection.

Corrosion is more than rusting: it is the electrochemical reaction of base metals with oxygen or other components from the environment. To stop this process, chromates are used in aerospace, for example, but they are toxic, carcinogenic and harmful to the environment. In the search for chromate-free alternatives, the Fraunhofer ITWM contributes its expertise in the two departments "Optimization" and "Image Processing".

Project Manager Dr. Natalia Konchakova (HEREON) visited Dr. Katja Schladitz (left) and Dr. Peter Klein at the Fraunhofer ITWM.

Turning Pollutant into Advantage

The outer skin of aircraft is damaged by stone chipping, for example, and thus suffers cracks and scratches through which water penetrates. This leads to corrosion. "The idea: to turn water as a source of danger into an advantage, namely by using anti-corrosion pigments that react with water and release ions that close the crack," says Dr. Katja Schladitz from the "Image Processing" department. With each scratch, channels are created through which the water flows in, but also out again. In the process, it dissolves the anti-corrosion pigments consisting of salts from the coated outer skin of the aircraft and repairs it layer by layer. The crack virtually closes itself when the aircraft is left in the rain for a certain period of time. "Active-reactice" is the name given to this mechanism.

The VIPCOAT researchers want to find out exactly how the optimal layer is composed by reproducing the microstructure of chromate-free coatings, including the transport channels, and optimizing the composition. Information about the size, shape and arrangement of the corrosion inhibitors is obtained from 3D images taken at the German Electron Synchrotron (DESY) in Hamburg.

Detect Particles

The preparation of the paint samples and their 3D imaging are complex because the particles are very small. In order to correctly capture their shape, one has to resolve them extremely high. This end very small samples (100 µm diameter) have to be prepared and placed stably for measurement. In the resulting 3D images, the particles have to be identified. This step is also complex because the sizes vary greatly, but the gray values of different types of particles are sometimes identical or do not differ significantly from that of air.

www.itwm.fraunhofer.de/pr-vipcoat1

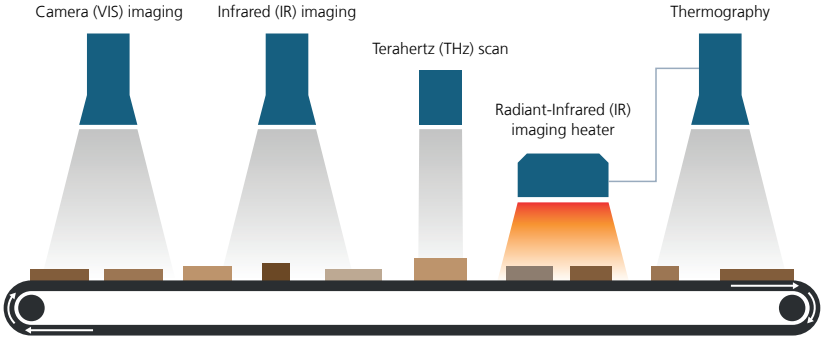
Recycling that's easy – with ASKIVIT save more wood from bulky waste

Some valuable raw materials are hidden in our bulky waste: non-ferrous metals, as well as wood and wood-based materials can be found in mountains of old cupboards. Recycling of these materials is useful from both an economic and an ecological perspective. In the "ASKIVIT" project, our researchers are developing an automated sorting system of bulky waste that is based on various imaging and processing techniques as well as artificial intelligence (AI).

In Germany alone, two million tons of bulky waste are generated every year. But not all of it is waste: depending on the regional disposal concept, up to fifty percent of the bulky waste consists of wood. This raw material is increasingly in demand; in order to protect the ecologically valuable forests from excessive deforestation, the use of waste wood is becoming more and more important.

Manual selection of wood-containing parts from bulky waste is both costly and error-prone. Our researchers in the "Material Characterization and Testing" department seek to pursue the goal of ASKIVIT project: an intelligent system that sorts bulky waste accurately and without fatigue – even without the prior shredding.

Four different imaging methods are used successively in the measurement setup. The acquired images are analyzed by AI algorithms.



Terahertz Technology Allows You to See More

Valuable raw materials are not always directly visible: the materials to be recycled are often hidden by fabrics, such as upholstery. Techniques that only look at the visible surface are therefore not sufficient when examining bulky waste. "We therefore use a terahertz sensor that also detects hidden objects," explains Dr. Dovile Cibiraite-Lukenskiene from the project team. The terahertz sensor, which is designed as a line sensor, makes it possible to scan through non-metallic covers and thus create a kind of 3D image of the object.

An important part of our scientists' research work is to adapt the sensor geometry as well as the reconstruction algorithms to the irregular conditions of the bulky waste. Therefore, at the beginning of the project, the terahertz sensor will be used on well-defined samples, and later on actual bulky waste in a sorting plant.

One Common System

In order to reliably examine bulky waste, ASKIVIT combines several techniques – and several research institutes in the process. In

"Utilization pressure on wood as a resource is increasing and prices are rising. The development of new sources of waste wood is therefore crucial for the raw material supply of the wood-based materials industry."

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Dr.-Ing. Jochen Aderhold
Fraunhofer Institute for Wood Research, Wilhelm Klauditz Institute, WKI

addition to our terahertz sensor, other imaging techniques are used:

- conventional imaging technology in the visible spectral range (Fraunhofer IOSB)
- near-infrared spectroscopy (Fraunhofer IOSB)
- active heat flux thermography (Fraunhofer WKI)

Initially, each institute will develop and test its own technique; the goal of the project is to combine the individual techniques into a common system. With this future system, in which four different imaging techniques are used in succession, wood-containing parts will be reliably detected and classified using artificial intelligence. The AI algorithms are contributed by the Institute for Industrial Information Technology at the Karlsruhe KIT.

Economic Advantages

"With ASKIVIT, significantly more wood will be detected in bulky waste – and with less energy and personal resources than was previously required," explains Dr. Dovile Cibiraite-Lukenskiene. The disposal companies benefit from the cost-efficient sorting as well as the increased amount of raw materials recovered. In addition, the wood-based materials industry becomes less dependent on fresh wood and companies that produce or process materials also benefit from the broader raw material base and increased efficiency in recovered wood.

www.itwm.fraunhofer.de/ASKIVIT_en

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Product Design Revolutionized by Programmable Materials

Research gives materials new extraordinary capabilities. The Fraunhofer Cluster of Excellence Programmable Materials CPM has been ensuring this since 2018. A team of seven around PD Dr. Heiko Andrä, Deputy Head of the Department "Flow and Material Simulation", provides the appropriate mathematics, simulation and optimization expertise from Fraunhofer ITWM.

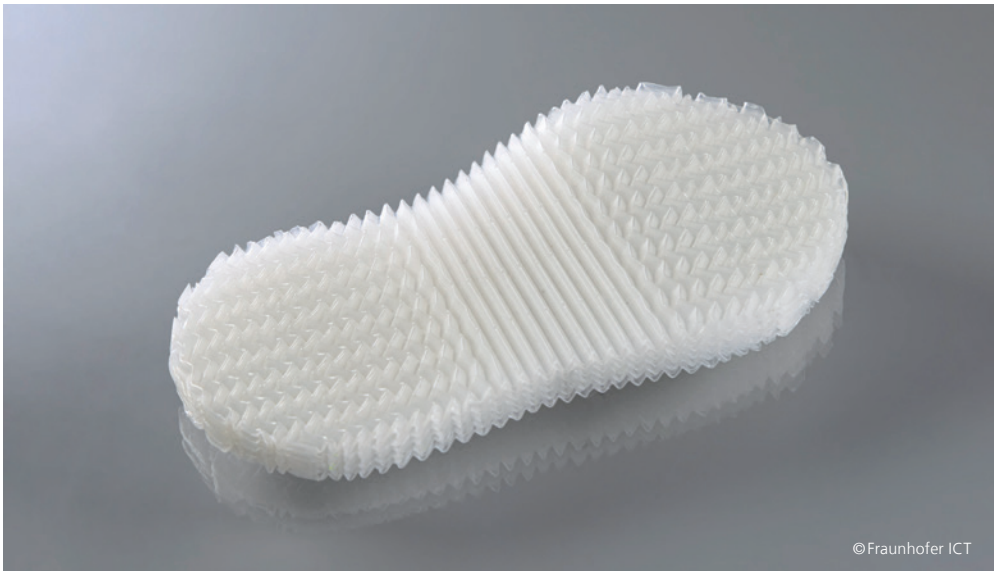
Running shoes with built-in cushioning that automatically adapts to the surface – whether forest floor or asphalt. Car seats that adapt to body tension or exterior components that quickly soften when they crash into pedestrians. Sound like dreams of the future? The cluster is about nothing less than the future of new materials.

In the Fraunhofer CPM, the competencies of various Fraunhofer institutes are bundled and work is carried out on various projects on the topic of "programmable materials". After four years, the first funding phase has ended. Since then, a lot has happened, also in the ITWM team.

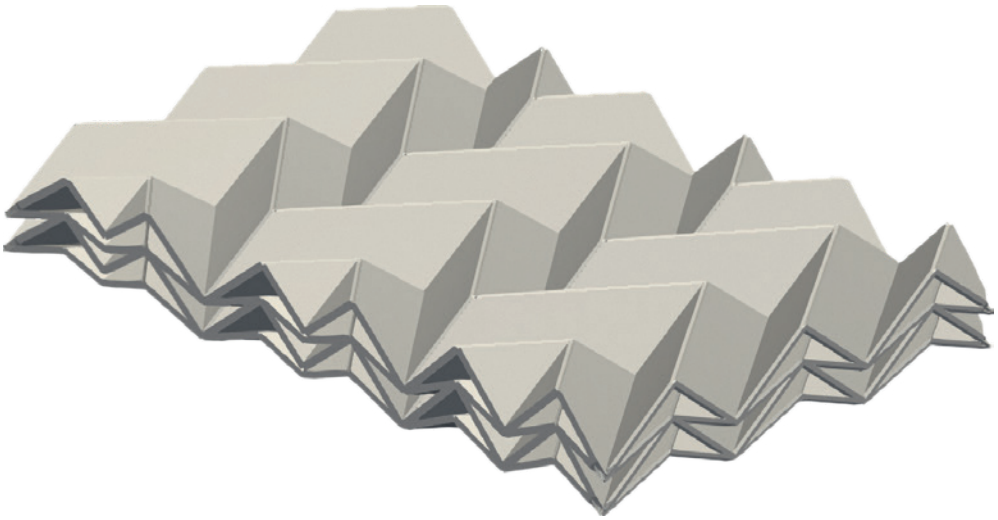
The Inner Values Count

New manufacturing processes such as 3D printing make it possible to produce targeted programmable structures in the micrometer range that have previously been developed on a computer.

In the case of "programmable materials", it is the internal structure that is important; through it, properties can be specifically controlled and the material behavior can change reversibly. Internally, they consist of a three-dimensional arrangement of many small individual cells. These serve as basic elements, are also called unit cells, and assemble them to



The Future of Materials: Product Design of a Plastic Sole Made of Programmable Material



Origami mathematics: The individual cells are folded elements made of plastic foils.

form two- or three-dimensional lattices. In their development, the researchers are taking their inspiration from nature. Because just like there, each cell not only has its own structure, but also properties and functions that make up the material as a whole. The arrangement of thousands of cells offers options for designing novel materials with local behavior that adapts to external conditions. What makes the materials so special is that they respond to specific triggers from outside. Such switching triggers include temperature, load or humidity. But what do companies gain from this development?

Software Tools Make Developments Ready for Industry

"In our ideal scenario, an engineer comes to us with certain desired functions of the product, and our tools help to find a combination of unit cells so that the material composed of these specific unit cells performs the desired function," Andrä explains. "For this purpose, the ProgMatDesign and ProgMatSim software tools have been created in the CPM, which enable virtual experimentation by selecting and arranging the cells."

With the help of optimization methods, each individual location in the component is given different parameters. The researchers from Fraunhofer IGD, Fraunhofer IWU and Fraunhofer ITWM are providing a web-based graphical user interface (ProgMatDesign) for designing the unit cells and programmable materials – it's easier to use than usual CAD software. "We are also building a database, where all the information on unit cells can be found, effectively the blanks for building the material. Using our in-house developed tool ProgMatSim, structures with optimal design are computed and used directly as input for 3D printing." A team then prints and tests the finished material, and it is recomputed if necessary. "Because it's not quite as ideal as in the digital twins yet realizable in practice on the 3D printer. The material sometimes warps or there are other interference aspects that don't show up in the virtual twin," Andrä says. But the mathematician is confident.

Mathematical Origami Art

Fraunhofer CPM is currently working on the scientific foundations and identifying potential applications of programmable metamaterials. In the process, cross-institute teams are also creating shape-morphing materials, which look like art, such as the origami materials that take on a desired shape when you pull on them. The individual cells are folded elements made of plastic films. In his doctoral thesis, Tobias Lichti, with the support of the Fraunhofer ICT and IWM, is computing the optimum size of the fold for each cell so that the origami material finally takes on the desired shape. This would not be possible without mathematics – in the end, the folded structures are hopefully at least as useful as they are beautifully shaped.

www.itwm.fraunhofer.de/programmable_materials

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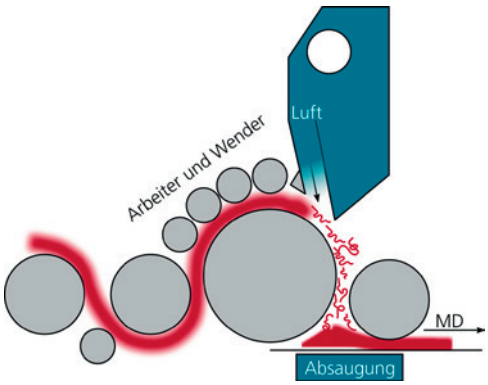
How Solutions From Our Departments "Flowed Together" in "ViDestoP"

Nonwovens are versatile and can be used in a wide range of applications – for example in medicine as protective clothing or in car interiors. Demand for the fabrics is growing, and with it the requirements for product properties. In an increasingly complex industry, the optimization of manufacturing processes is a key competence, which our researchers are addressing across departments in the "ViDestoP" project (Virtual Design and Stochastic Prototyping).

3 Departments, one project and a whole chain in view

Today, process and product optimization is usually carried out by trial-and-error tests directly on the production lines. This is a costly and time-consuming process due to the necessary production interruptions. In some areas of nonwovens production, digital twins and software solutions from our institute have already enabled virtual optimization. The interdisciplinary ViDestoP team has now extended the focus to the entire production chain.



Sketch of the airlay nonwoven production process

Simulation of Process and Product Properties

In the production of nonwovens of any kind, the interactions that occur between the fibers and air flows are particularly important for the end product. In the so-called "airlay process", individual fibers are first extracted from the plastic raw material and then swirled together by an air flow with the aid of a large cylinder. The highly turbulent air flow then deposits the fibers on a conveyor belt. There, they are compressed into a nonwoven fabric by an air suction system and further processed. Depending on the material and process properties, different nonwovens are produced in this way.

Our "Transport Processes" department has been simulating these dynamics of fibers in turbulent flows with the software FIDYST (Fiber Dynamics Simulation Tool) for years, focusing on energy consumption and fiber deposition on the conveyor belt. For the simulation of mechanical and thermal material properties, our "Flow and Material Simulation" department has also used the digital material laboratory GeoDict. The software can be used, for example, to calculate nonwoven properties such as permeability or conductivity and much more. In the ViDestoP project, these established ITWM software solutions for the process (FIDYST) and the material properties (GeoDict) were combined to form an integrated solution. Project manager Prof. Dr. Simone Gramsch emphasizes: "ViDestoP has not only closed the chain of our simulation tools, but also strengthened the connection between the departments and completely new ideas have emerged."

Fiber Deposition as a Stochastic 3D Model Validated With 3D Printing

In the course of the process simulation, a novel 3D model was developed to represent the superimposition of the fibers, so that both the individual fiber deposition and the process parameters of the production plant are taken into account. With this model, it is possible for the first time to simulate a three-dimensional nonwoven with real thickness, width and a sufficiently large length. What then followed was new conceptual and methodological territory: to validate the simulated product properties, a team from the "Materials Characterization and Testing" department created 3D prints in various steps. Based on this work, the microscopic models of the simulations could in turn be adapted and refined. This procedure is called "stochastic prototyping", which also explains the title of the project.

Demonstrator as a Practical Test: Optimizing an Insulation Material

To prove the application of virtual design in optimizing nonwoven products, the researchers tested the process using a demonstrator. From the Design of Experiments (DoE), an optimal virtual microstructure for the insulation material was derived and validated by 3D printed fabrications. From this, clear conclusions for the manufacturing process can be derived in the industry. With this portfolio, the ViDestoP team is ideally equipped to support companies in the production of nonwovens by simulations in their questions through simulations.

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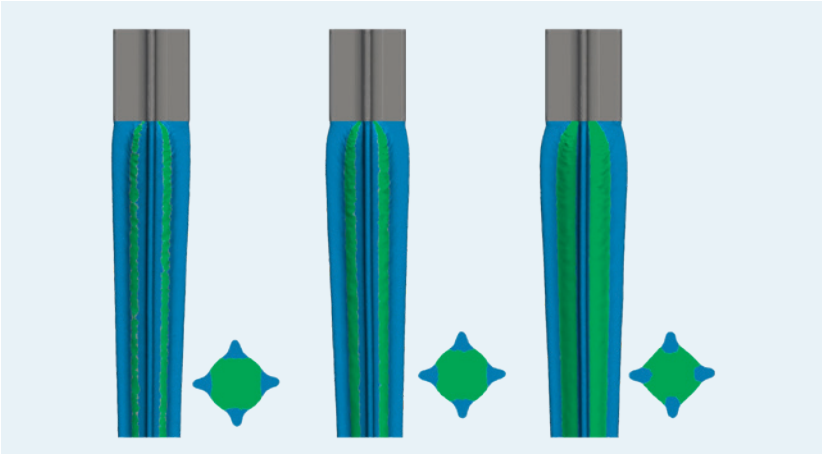
Extrusion Simulation of Bicomponent Synthetic Fibers

Not all fibers are round. But how do you make it run round anyway and spin a plastic fiber with a cloverleaf-shaped cross section, for example? A team from our department "Transport Processes" develops simulation methods for such complex tasks – our established software solutions MESHFREE and VISPI are used here.



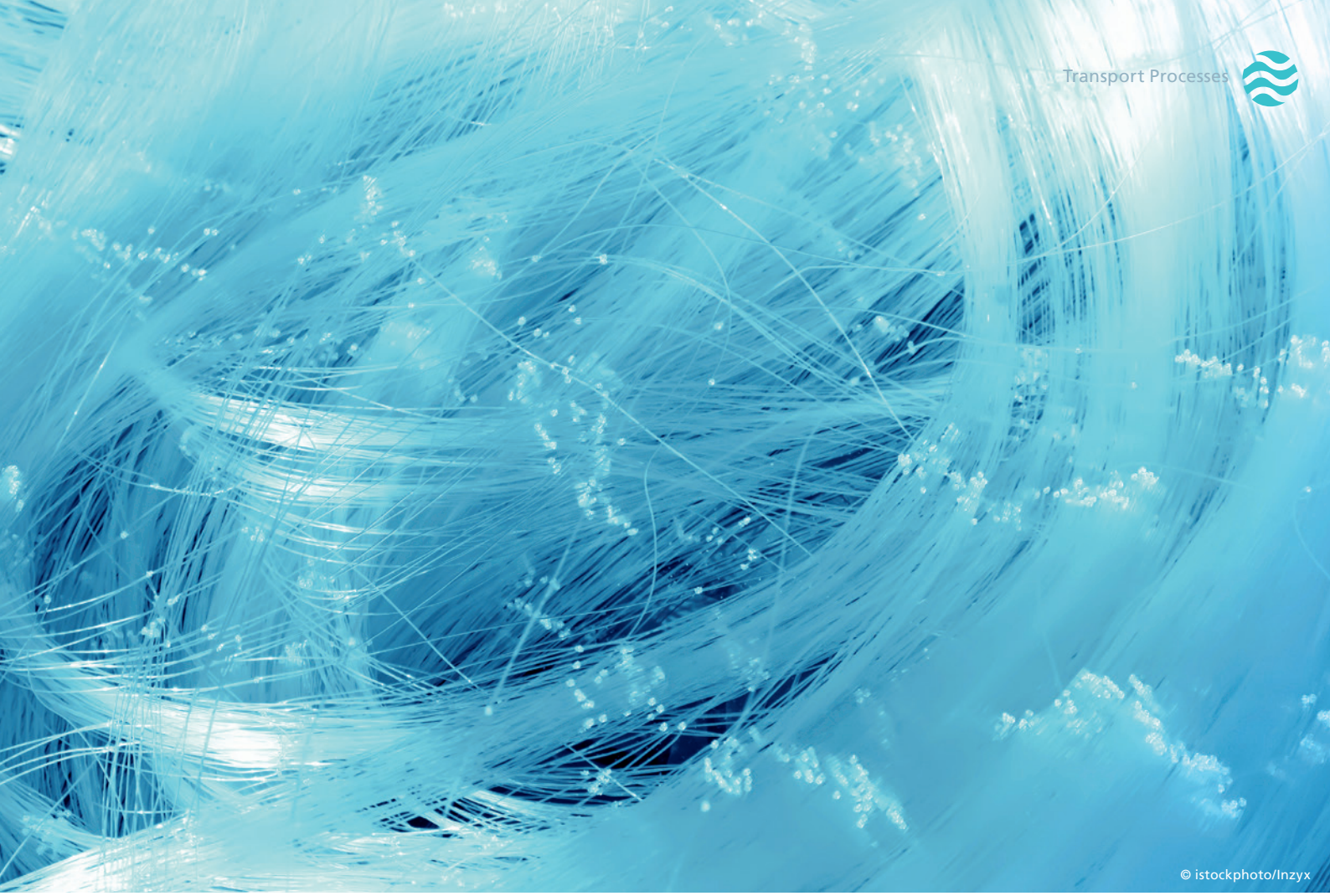
Three different BiGOFil fibers with different raw material properties: The graphic shows in each case the fiber spinning out of the die and the final fiber cross-section.

Today, everyday life without plastic fibers is unthinkable. We encounter them in almost all areas of life, whether in an oil filter or in a nonwoven medical face mask – and their composition varies depending on their function. In essence, however, they all depend on the fibers on a small scale and the production process on a large scale.

In spinning processes for the production of synthetic fibers, molten or dissolved mass is forced through fine nozzles and spun into fibers. These are usually passed through an air flow for curing. Known processes are melt spinning or dry spinning. What they all have in common is that it is always a demanding process in which all components must interact optimally. That is why our department "Transport Processes" has already developed software solutions that virtually map the spinning process as a digital twin. Such simulations save manufacturers cost- and time-intensive experiments, allow new insights and enable systematic parameter variations, which then support product design.

BiGOFil: Simulation of Plastic Fibers Using the Project Example

The work of the past decades has made our researchers world-leading experts in this field. Numerous projects have involved modeling, simulation and optimization. One example is the two-year BiGOFil project, which will be completed in 2022. Coalescence filters are used, for example, to filter fine oil droplets from an air flow. We are supporting our project partners in the development of special bicomponent fibers that are added to the filter to better drain off the collected oil. The shape of the fibers is particularly important for the



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functional properties, which we can influence by designing the fine capillaries of the spinneret.

"We use two of our established ITWM tools and thus achieve an unprecedented simulation depth," says Dr. Christian Leithäuser, project manager BiGOFil. "Our VISPI solution simulates the spinning process as a whole. In the next step, our software MESHFREE is then called upon. It takes over the mesh-free detail simulations of a single fiber. In the process, several areas and properties can be taken into virtual view at the same time. For example, the temperature curve influences the shape and properties of the finished fiber.« The researchers then reflect the findings from this micro view back to the macro level: What does the fiber look like in the simulation and how must the nozzle therefore be designed?

Outlook: New Challenges From Bio-Based Materials

The portfolio expansion of the ITWM team can not only be applied to plastic fibers for filters, but may also help in the production of bio-based plastics in the future. The majority of materials produced so far are based on petroleum. That is set to change.

"One alternative, for example, is materials that are partly made from renewable raw materials and/or are biodegradable. Here, the industry is constantly looking for ways to replace the classic raw materials. Processing these novel materials is a challenge. This also requires modified production processes." Processes that the team will certainly be able to support with digital twins in the future.

www.itwm.fraunhofer.de/tv-process-design

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Process Engineering: Using AI for Industrial Processes

It is one of the great visions of the "Optimization" field: to make the next level of artificial intelligence (AI) usable for process engineering. In doing so, the researchers want to penetrate completely new regions.

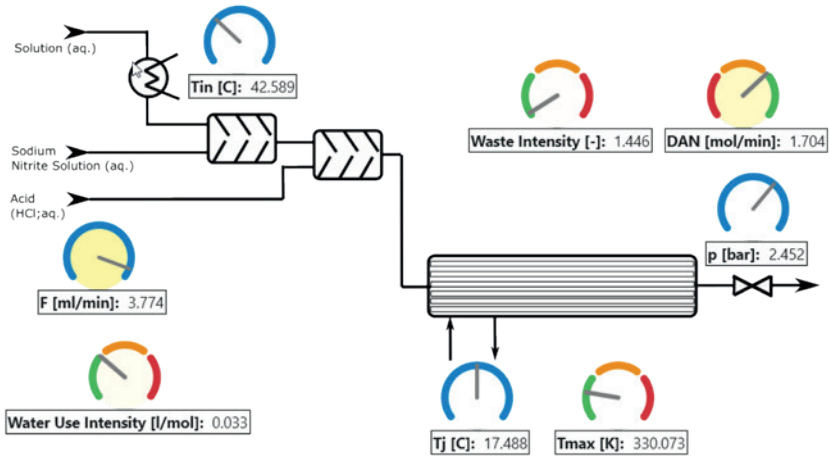
Whenever raw materials become a product, process engineering is used. Processes in this branch of industry are usually tried and tested over many years. The decision to intervene in work steps must be well thought out – wrong decisions can not only change the quality of a product, but also cause high costs.

AI Should Show Potential for Improvement Show

"AI is now very good at describing actual states," says Prof. Dr. Michael Bortz, head of the "Optimization – Technical Processes" department, and illustrates this with the example of speech recognition as used on cell phones: "It recognizes words that the user uses frequently and therefore suggests them as soon as he starts writing a certain sequence of letters. So the system is individually trained by the user and learns."

If AI is to be used to optimize production processes, there is more to it than that: optimization means finding combinations of degrees of freedom that lead to better results than those known to date. This requires rigorous physical models and optimization algorithms that come as close as possible to potential improvements. "The goal is for AI in process engineering to recognize where there is potential for improvement and thus provide the most concrete clues possible to take a closer look at specific processes," says Bortz. "Figuratively speaking: If I'm standing in the Alps and want to reach the highest point, AI should be able to tell me where to start from and how to reach the destination. Efforts to climb the second highest mountain only to see from there that there is an even higher one is not a satisfying result."

Schematic flow diagram of a chemical production process



Successful Projects Pave the Way

Bortz's team has gained experience in developing rigorous models for reliable, realistic predictions for the chemical company BASF SE, among others: In projects that have since been completed, a user-friendly interface to historical process data was created for a flowsheet simulator in order to calibrate the data for forecasts. In a current collaborative project, the aim is to use AI to numerically evaluate the processes calibrated in this way as

The main plant of BASF SE in Ludwigshafen is the largest contiguous industrial complex in Europe. Fraunhofer ITWM is currently working with BASF SE in a joint project to realize virtual "what-if scenarios" with the help of AI.

effectively as possible, enabling users to quickly and intuitively realize virtual "what-if" scenarios. In this way, the effects of changes can be simulated before they are actually implemented.

AI Projects Underway

Bortz's team is also exploring the possibilities of AI for process engineering in the KEEN project (AI incubator labs in the process industry) – an innovation platform for the chemical industry that brings together startups, corporations and research institutions. Fraunhofer ITWM provided the first software prototypes as part of the project last year. For one of these, a neural network was trained in such a way that the software enables engineers to reverse forward planning. That is, instead of changing certain factors and then checking their impact on the product, it answers the question, "Here's what I want the product to be, how do I need to run the plant to get it?"

Bortz rates the potential of AI for process engineering as definitely high because, "In numerically complex simulations, information about where to look can save a lot of time. The more precise this information is, the more concretely we can provide assistance and optimize processes."

More information at www.itwm.fraunhofer.de/projectkeen

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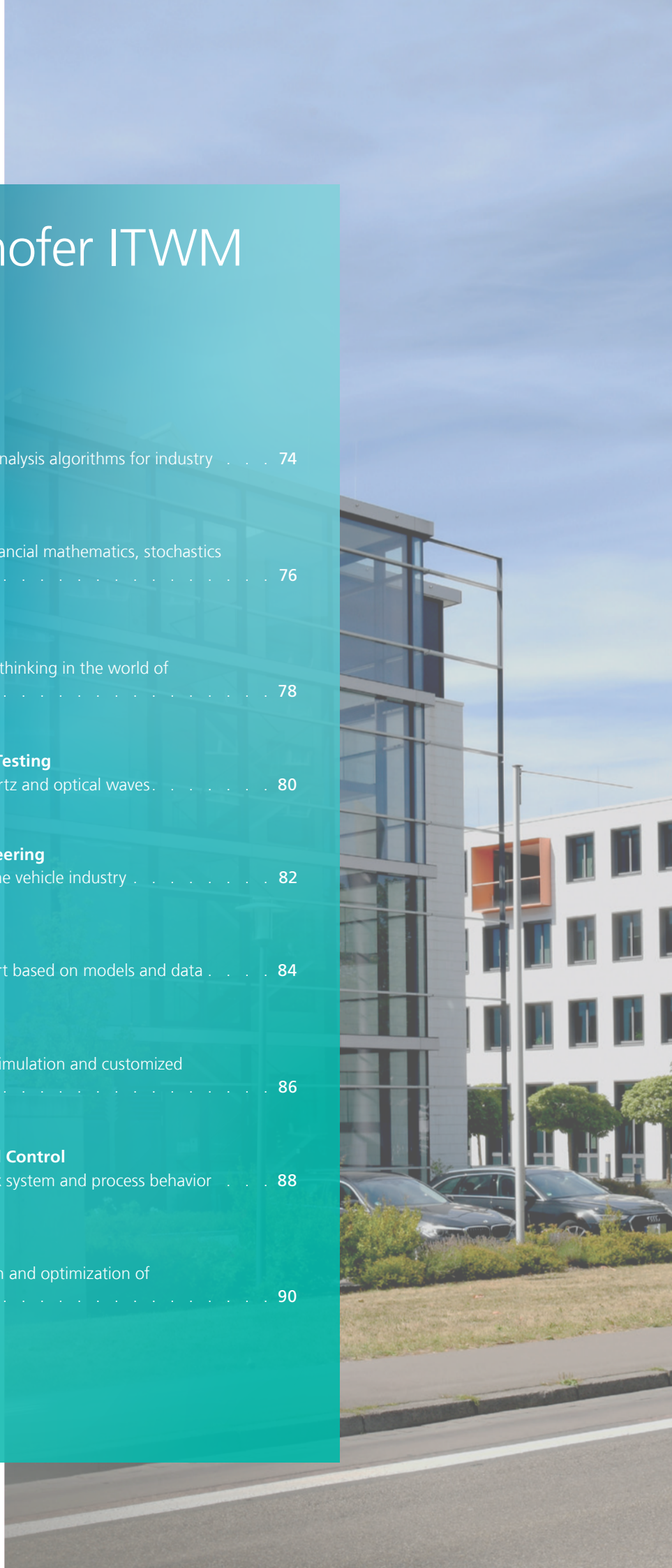


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Main Focus

- Surface and Material Characterization
- Quality Assurance and Optimization
- Virtual Image Processing
- Industrial Image Learning
- Quantum Image Processing
- Condition Monitoring and Predictive Maintenance

Image Processing

What does your department deal with and what constitutes its research work?

Our department develops image analysis algorithms and converts them into industrial-grade software in production. The application areas include sophisticated surface inspection and analysis of microstructures. We develop both new methods and domain-specific machine learning algorithms.

What potential does your department's research have for a better future?

Many methods, especially AI processes, enable savings in resources and energy in production. These topics are becoming increasingly important. But also tasks related to nature conservation and sustainability are solvable by our algorithms.

Where do you see your department in five years?

In five years, AI algorithms will be used in all industrial projects of our department, but also linked to model-based approaches. Many complex quality tests will only become possible in the next few years as a result of developments in AI and hardware. Sustainability issues will become as important as other industry goals, such as cost savings, higher production speed or less waste.

Which three keywords best describe your department?

- Industry-oriented – pragmatic – goal-oriented

Department topics in this report:

www.itwm.fraunhofer.de/en/bv

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Main Focus

- Billing Audit
- Retirement and Life Insurance
- Flexible Loads on the Energy Market
- Data Science
- Quantum Computing

Financial Mathematics

What does your department deal with and what constitutes its research work?

We simulate pension contracts and optimize investment strategies for life insurance policies. We use statistical methods and data science to identify anomalies in billing. And we save costs and energy by optimizing load shedding.

What potential does your department's research have for a better future?

We have broad expertise in fraud prevention and also the right software, for example in the billing of care services. The same applies to secure financial markets, also with regard to consumer protection. Saving energy is a key social and economic issue. We take this into account with our work on the flexible use of energy in industrial companies.

Where do you see your department in five years?

We have continued to expand our expertise in current research areas. Since quantum computers have demonstrated their superiority over classical computers and we are already conducting research in this area, we will be an established partner for applications of quantum computing in the financial industry. Presumably, we have other research fields that are not yet visible to us today.

Which three keywords best describe your department?

- Team spirit – success – fun

Department topics in this report:

www.itwm.fraunhofer.de/en/fm

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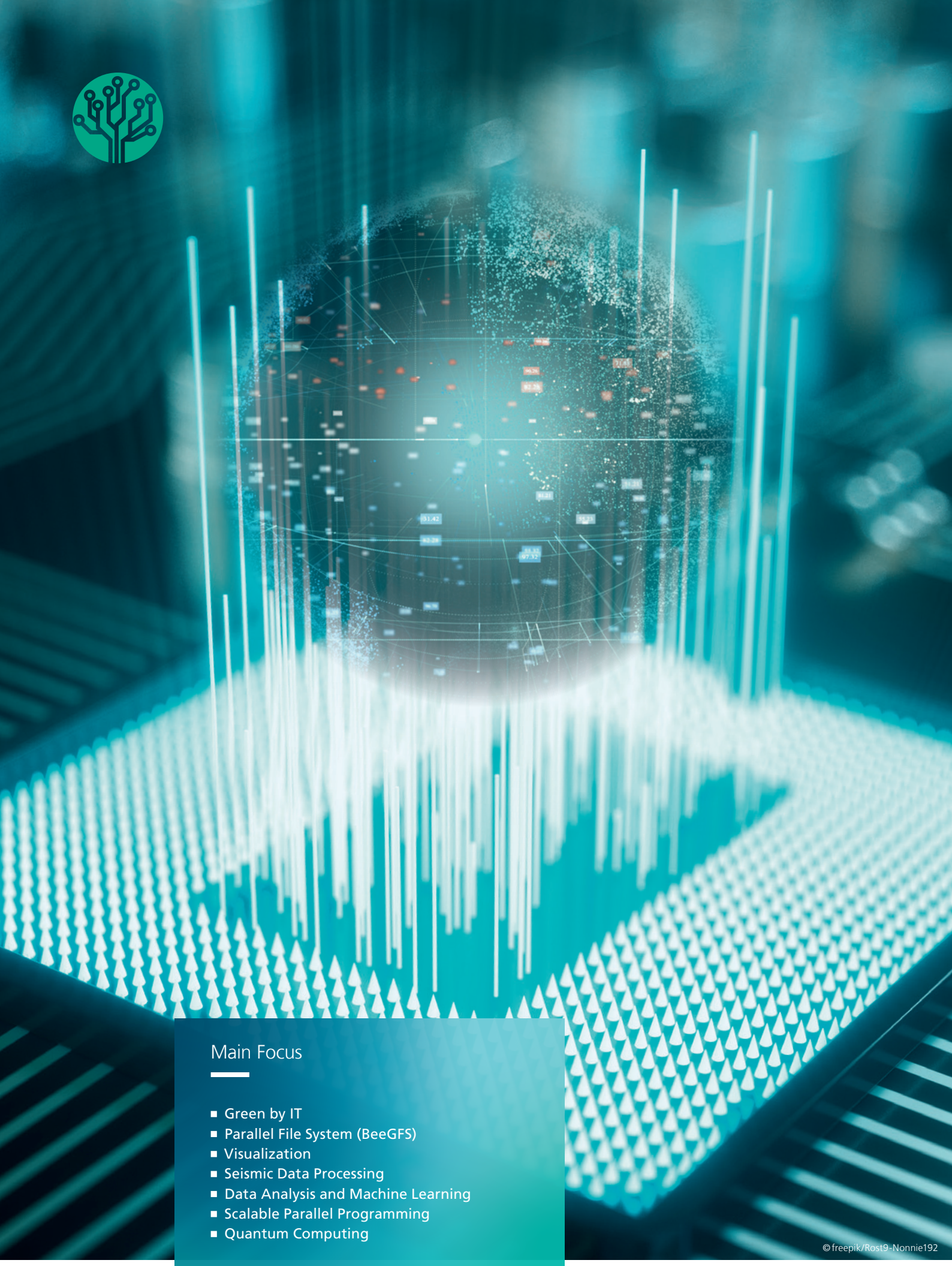

Main Focus

- Green by IT
- Parallel File System (BeeGFS)
- Visualization
- Seismic Data Processing
- Data Analysis and Machine Learning
- Scalable Parallel Programming
- Quantum Computing

High Performance Computing

The High Performance Computing leadership team consists of Dr. Valeria Bartsch, Dr. Norman Ettrich, Dr. Daniel Grünewald, Dr. Janis Keuper, Matthias Klein-Schlößl, Dr. Jens Krüger, Dr. Mirko Rahn and Dr. Rui Màrio da Silva Machado. In the following Dr. Valeria Bartsch and Dr. Jens Krüger, as spokesperson, will answer the questions:

What does your department deal with and what constitutes its research work?

We are a globally recognized partner when it comes to the development of new technologies especially for distributed and high-performance computing. We are committed to holistic and future-oriented development, optimization and research. Our topics include efficient and scalable hardware and software solutions, as well as methods for addressing industrial and societal challenges.

What potential does your department's research have for a better future?

We drive the current state of the art in high performance computing. We are courageous and break new ground when it comes to novel solution. We are not afraid to think outside the box and we are making a decisive contribution to the transformation to a sustainable society.

Where do you see your department in five years?

We will have developed a complete supercomputing hardware and software stack. We integrate quantum computing into HPC systems successfully. We are open to the unexpected and will develop new ideas over the next five years.

Which three keywords best describe your department?

- Holistic – sustainable – courageous

Department topics in this report:

www.itwm.fraunhofer.de/en/hpc

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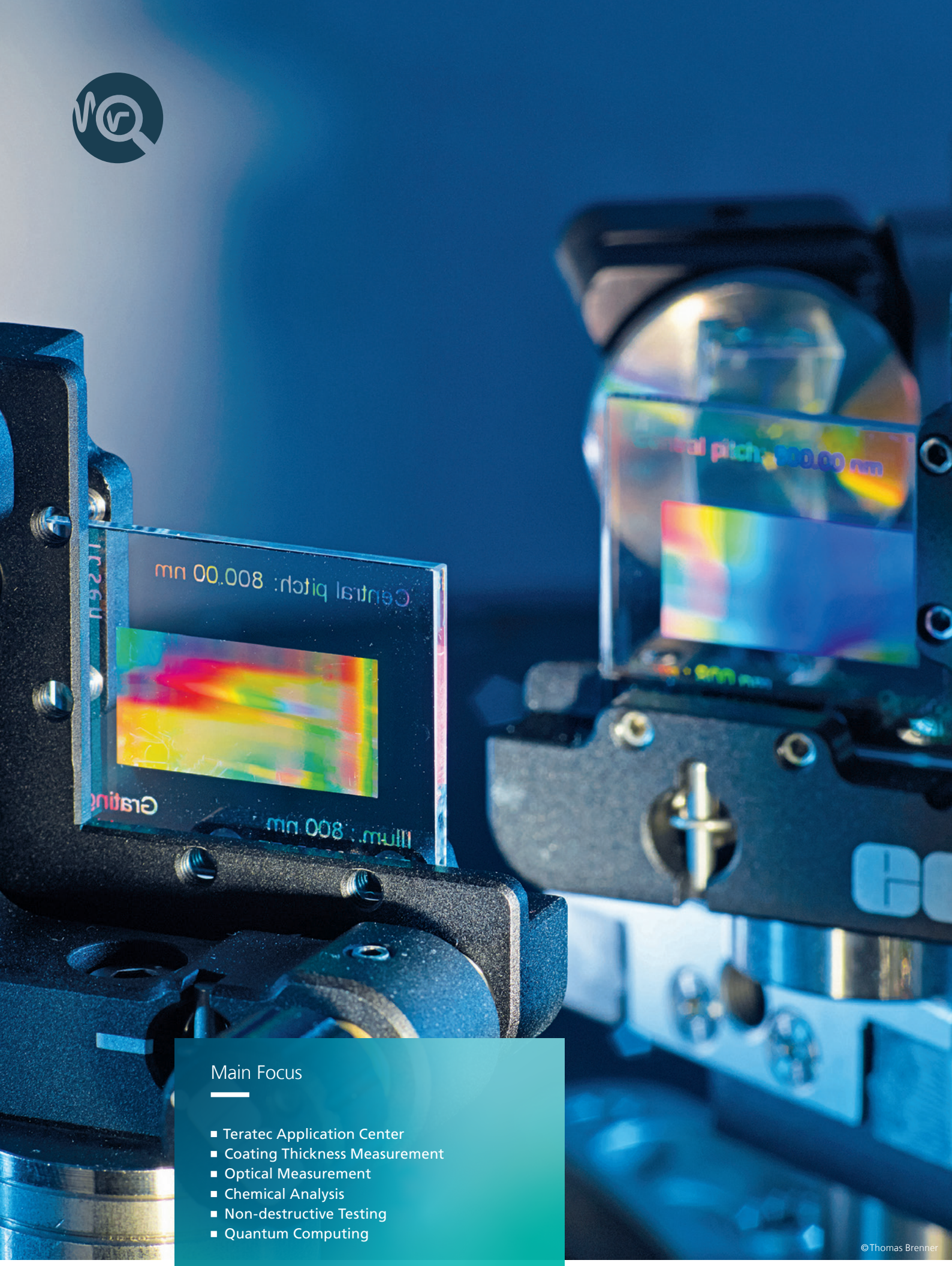

Main Focus

- Teratec Application Center
- Coating Thickness Measurement
- Optical Measurement
- Chemical Analysis
- Non-destructive Testing
- Quantum Computing

Materials Characterization and Testing

What does your department deal with and what constitutes its research work?

Our work focuses on non-destructive testing for quality control in the industrial manufacturing process. Our applications range from pipe wall thickness measurement to the characterization of multilayer coating systems and insulation around wires. For this purpose, we use electromagnetic waves in the entire spectral range from visible light to the terahertz wave range and use both quantum-inspired measurement technology and the possibilities of machine learning to achieve the best possible results.

What potential does your department's research have for a better future?

Non-destructive testing and quality control reduces the number of defective parts. This saves companies time, money, and resources, and gives their customers the certainty of receiving products of the highest quality. Our systems are easy to operate and can be integrated into existing processes. This secures the basis for investment and jobs. Through our research, we generate innovations that guarantee the technological edge needed to survive in global competition.

Where do you see your department in five years?

The department continues to build on its leadership position for the use of terahertz technology in nondestructive testing and will expand it to include quantum-inspired measurement technology. Testing techniques will cover the entire spectral range and be supported by machine learning in evaluation to reliably identify the widest possible variety of defects. This will allow us to open up new application scenarios that are currently not within reach.

Which three keywords best describe your department?

- Customer-oriented – innovative – precise

Department topics in this report:

www.itwm.fraunhofer.de/en/mc

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Main Focus

- Digital Environmental Data
- Load Data and Durability
- Dynamics and System Simulation
- Human Models and Human-Machine Interaction
- Cables, Hoses and Flexible Structures
- Tire Models – CDTire
- Technical Center: Human Machine Interaction and Driving Simulators

Mathematics for Vehicle Engineering

What does your division deal with and what constitutes its research work?

The division is divided into two departments as well as the project group "Tire Simulation" and the cross-sectional unit "MF-Technikum", which takes care of the test and measurement technology.

In the department "Dynamics, Loads and Environmental Data", we develop methods and tools for system simulation, incorporating environmental data and usage variability. In this way, we address the main aspects in vehicle engineering: operational stability, reliability, energy efficiency and ADAS/AD.

The department "Mathematics for the digital factory# bundles the activities for the design of software tools for the virtual development of products; this includes, for example, IPS Cable Simulation: With this software family, the assembly of cables, cable harnesses and hoses can be designed virtually and validated in operation.

What potential does your division's research have for a better future?

Vehicle development is currently facing a number of challenges. In addition to the need to make product development and production more efficient, there is also the trend toward ever to ever more advanced assistance (ADAS) through to autonomous driving, as well as the development and qualification of alternative drive systems that are as emission-free as possible. The research focus of our division is geared to these three challenges.

Where do you see your division in five years?

Although the vehicle industry as a whole is going through a crisis, we believe we are well positioned with the focus described above. We expect the area to be in a good position both scientifically and economically in five years' time with three departments and the technical center.

Which three keywords best describe your department?

- Innovative – interdisciplinary – professional

Department topics in this report:

www.itwm.fraunhofer.de/en/mf

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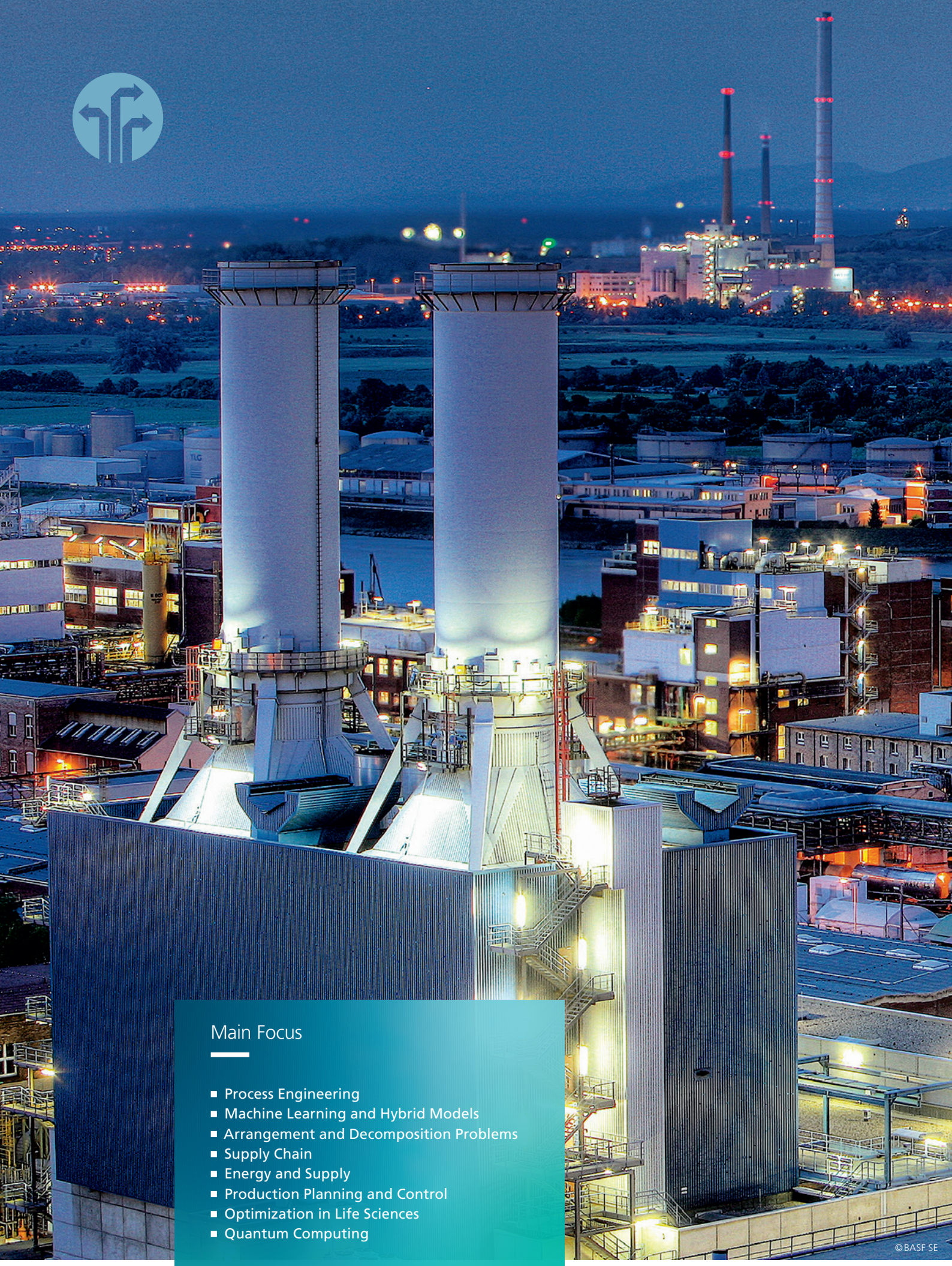

Main Focus

- Process Engineering
- Machine Learning and Hybrid Models
- Arrangement and Decomposition Problems
- Supply Chain
- Energy and Supply
- Production Planning and Control
- Optimization in Life Sciences
- Quantum Computing

Optimization

What does your department deal with and what constitutes its research work?

The "Optimization# area deals with the model-based simulation and optimization of complex technical and organizational processes. The goal here is to master complexity by making promising solutions interactively accessible. We make improvement potentials transparent and comprehensible, so that users can quickly recognize them.

What potential does your department's research offer for a better future?

The combination of knowledge-based and data-based approaches to model-based optimization holds enormous potential, precisely because data is available on an increasingly large scale. At the same time, the need for traceability and transparency in decision-making processes is increasing. Both are trends that we are happy to support.

In addition, we are positioned across all industries. This ensures stability as well as an exciting and interdisciplinary innovation climate.

Where do you see your department in five years?

The business unit keeps growing, largely thanks to long-term industrial partnerships. Surprising them again and again with innovative solutions and winning new customers is an important challenge. We also need creative minds who have high standards for innovative solutions and their implementation. If both succeed, "Optimization" will be able to further increase its visible impact.

Which three keywords best describe your department?

- Innovative – customer-oriented – with high standards for ourselves

Department topics in this report:

www.itwm.fraunhofer.de/en/opt

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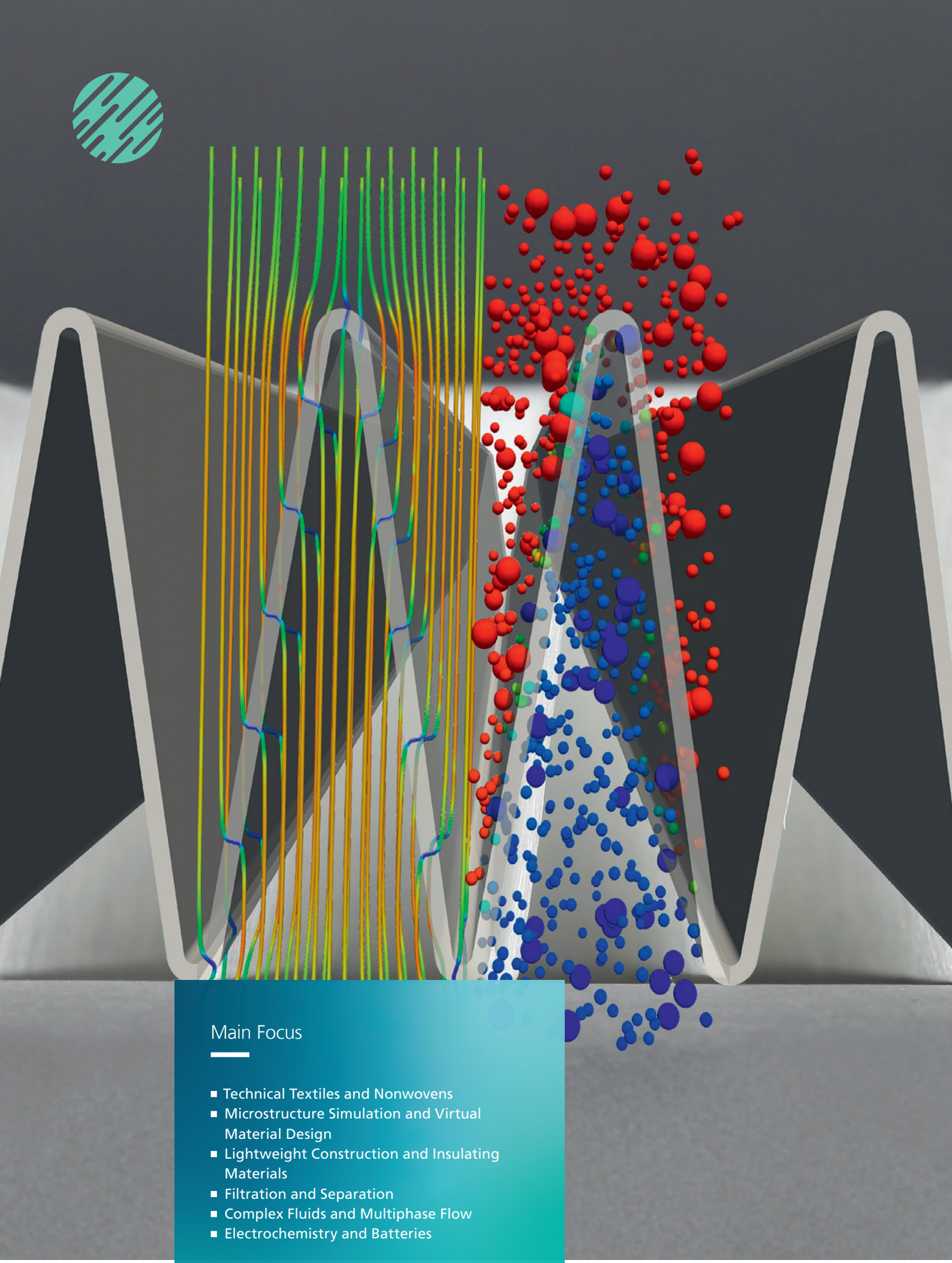

Main Focus

- Technical Textiles and Nonwovens
- Microstructure Simulation and Virtual Material Design
- Lightweight Construction and Insulating Materials
- Filtration and Separation
- Complex Fluids and Multiphase Flow
- Electrochemistry and Batteries

Flow and Material Simulation

What does your department deal with and what constitutes its research work?

We design and implement method and software solutions for the development, production and improvement of innovative, sustainable materials, including so-called programmable materials. In doing so, we develop industrially suitable multiscale and multiphysics methods and customer-specific software solutions. Our simulation tools use latest research results such as model reduction methods, automatic parameter identification and machine learning to increase efficiency.

What potential does your department's research have for a better future?

The digitalization of material development – from manufacturing to life cycle assessment and recycling – is accelerating the development of innovative, sustainable materials. This is demonstrated by our new projects on material substitution through biobased and biohybrid textiles, foams and composites in lightweight construction, efficient and alternative battery concepts for electromobility, and self-cleaning particle filters.

Where do you see your department in five years?

The aim of our method and software development is to enable our customers to digitally accompany the design of their sustainable products and the associated process development from start to finish in five years' time, i.e. to have so-called digital twins down to the material level. These enable rapid testing of variants and innovations, without having to produce real prototypes. Digital twins can also be used for the quantitative evaluation of raw material and energy balances. In this way, we support sustainability and conserve resources.

Which three keywords best describe your department?

- Multiscale – efficient – robust

Department topics in this report:

www.itwm.fraunhofer.de/en/sms

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Main Focus

- Power Generation and Distribution
- Real-time Plant Operation and Drive Technology
- Biosensors and Medical Devices
- Machine Learning
- Control of Complex Systems
- Model Identification and State Estimation

System Analysis, Prognosis and Control

What does your department deal with and what constitutes its research work?

We develop digital twins for real-time monitoring, predictive maintenance and energy-efficient control for production plants and drive trains. Together with our customers, we develop and adapt customized solutions using artificial intelligence methods. In doing so, we make use of the large toolbox with methods from signal analysis, system and control theory, automation, and machine learning.

What potential does your department's research have for a better future?

Many companies are ready for digitalization. The volume of different data and information that this generates opens up the possibility for us to develop innovative, precisely tailored solutions for the sustainable operation of production plants and drive trains. This enables the simultaneous optimization of quality and quantity, the efficient use of energy and raw materials, and the condition-oriented operation of production plants and drive trains.

Where do you see your department in five years?

In Five Years, the department will offer even more holistic solutions – from supporting the integration of sensors and actuators to implementing custom-fit methods and algorithms on embedded systems or in microelectronic devices.

Which three keywords best describe your department?

- Innovative – close to hardware – experienced

Department topics in this report:

www.itwm.fraunhofer.de/en/sys

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Main Focus

- Flexible Structures
- Fluid Dynamic Process Design
- Lattice-Free Methods
- Energy Grids and Model Reduction

Transport Processes

What does your department deal with and what constitutes its research work?

We model complex industrial problems and develop efficient algorithms for the numerical simulation and optimization of these problems. The problems are mostly in the context of fluid dynamics, structural mechanics, radiative transfer, optics etc. From the point of view of our industrial customers, it is about the design of production processes and the optimization of products.

What potential does your department's research have for a better future?

Techniques for automatic differentiation allow the identification of systems and their optimization with previously unimaginable quality and efficiency – it was this background that made it possible to develop epidemiological models for an extremely dynamic infection event with the start of the Corona pandemic. For industry, we have created MESHFREE, a software that describes processes and products with complex and highly variable flow dynamics very well. Current urgent problems such as energy grids and energy efficiency have played a have also played a relevant role in our research for years.

Where do you see your department in five years?

We will increasingly develop, use and license our own software tools. The associated growth requires adapted structures, which will be implemented in the course of the upcoming change in department management.

Which three keywords best describes your department?

- Flexible methods – problem-oriented – customer-oriented

Department topics in this report:

www.itwm.fraunhofer.de/en/tv

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