University of Stuttgart

forschung leben

September 2021

Producing the Future

Advanced manufacturing

New architecture
Fibers for sustainable construction

Concentrated innovative capacity
Center for the industry of the future

Biointelligent systems
Nature as a production model

Prof. Wolfram Ressel

“We are currently experiencing a fundamental transformation in modern production engineering, one of the scientific fields in which the University of Stuttgart is deeply involved – a paradigm shift in fact.”

Photo: Matthias Schmiedel

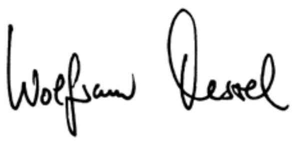
Prof. Wolfram Ressel
Rector of the University of Stuttgart

Dear Reader,

A while ago, a trade magazine for additive manufacturing published an article under the title “Advanced manufacturing is dead – long live advanced manufacturing.” That may sound slightly exaggerated, but we are currently experiencing a fundamental transformation in modern production engineering, one of the scientific fields in which the University of Stuttgart is deeply involved – a paradigm shift in fact: keywords and terms such as real sustainability rather than “greenwashing,” digitalization and Industry 4.0 – maybe even 5.0 or 6.0 by now – software-defined manufacturing, mass personalization, as well as biotechnology and biointelligence represent a development that not only affects all areas of production and value creation chains, but also has a profound impact in the working environment and, indeed, in the whole of society.

In this issue of “forschung leben”, which focuses on “Producing the Future”, you’ll read about the many ways in which the University’s researchers are driving this transformation by such means as an interdisciplinary understanding of advanced manufacturing at the Stuttgart Center for Production Technology, the new Center of Excellence for Mass Personalization, the “Mobility of the Future” innovation campus and the Biointelligence Competence Center. And don’t miss the pithy guest article by Dr. Eberhard Veit, an expert in innovation who is also calling for radical change in corporate leadership.

Yours sincerely,



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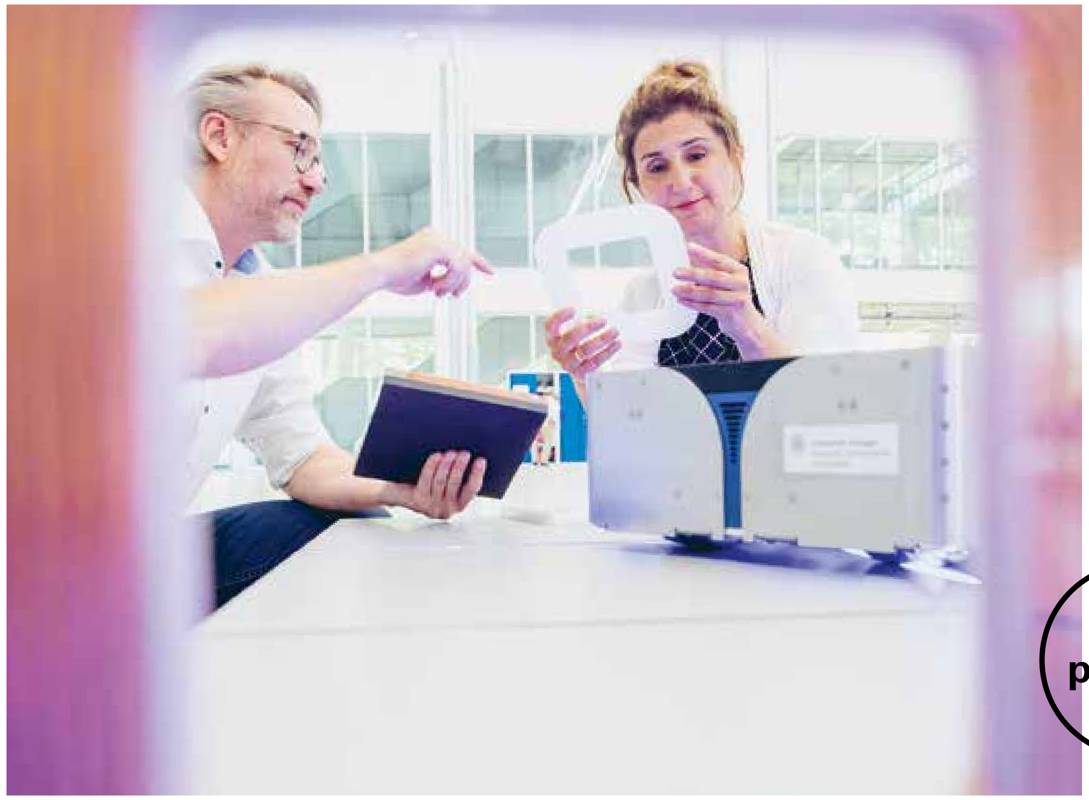
Concentrated innovative capacity



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EXPERIENCE RESEARCH

Wireless commodity flow

Photos: p. 1 and 84 xiaoliangge/stock.adobe.com, p. 4 University of Stuttgart/IntCDC, p. 5 Max Kovalenko, Uli Regenscheit

NOTE PAD

AWARDS

ERC ADVANCED GRANT

Prof. Tilman Pfau received an ERC Advanced Grant from the European Research Council for his research in the field of fermionic matter with long-range interactions. This highly prestigious prize is awarded to scientists who have achieved groundbreaking research results during the past ten years.

Strongly interacting Fermi gases occur naturally at the tiniest to the largest scales – from atomic nuclei to neutron stars. Pfau's aim is to gain a profound, microscopic understanding of the underlying physics of strongly correlated fermionic quantum matter, whose interactions take place over distances that can only be resolved with new microscopy methods, whereby he and his team are employing two innovative quantum gas microscopy methods, which are able to detect strong dipolar quantum correlations in lattices and bilayers, as well as fermionic correlations around impurities and charges.

IBM QUANTUM OPEN SCIENCE PRIZE

PhD student **Sebastian Brandhofer** of the Institute of Computer Architecture and Computer Engineering (which is headed by Prof. Ilia Polian) and postdoc **Dr. Daniel Bhatti** and master student **Jelena Mackeprang** of the Institute for Functional Matter and Quantum Technologies (Prof. Stefanie Barz' working group) have all been awarded the inaugural IBM Quantum Open Science Prize. Their challenge was to reduce errors in a quantum computing task thereby helping to make quantum algorithms more reliable in the near future. The prize was won by four teams, who shared the USD 50,000 endowment. This success was due to the collaborative, interdisciplinary efforts of researchers working in the fields of computer science and quantum physics.

TOP POSITIONS IN THE SHANGHAIRANKING

ShanghaiRanking Consultancy's Global Ranking of Academic Subjects(GRAS) is a major university ranking scheme with an international profile. In the latest edition, three University of Stuttgart faculties were ranked top in a Germany-wide comparison, two of which were even ranked among the Top 50 worldwide.

The University of Stuttgart's Mechanical Engineering and Civil Engineering Departments, for example, scored the highest number of points in a German-wide comparison. The departments performed just as impressively at the international level, where they were ranked 44th (Mechanical Engineering) and 46th (Civil Engineering) in the Top 50 out of hundreds of universities around the world. The University of Stuttgart can also be satisfied by its ranking in the "Automation & Control" category: whereas it finished between 101st and 150th in the worldwide ranking, it was ranked third in Germany.

MANFRED HIRSCHVOGEL AWARD 2021

Dr. Larissa Born, a research assistant at the Institute for Textile and Fiber Technologies (ITFT), was awarded the Manfred Hirschvogel Prize 2021. The 5000 euro prize is awarded annually at all TU9 universities for the best dissertation in the field of mechanical engineering. Her award-winning doctoral thesis is entitled "Basic principles for the dimensioning and design of a hybrid material for exterior adaptive façade components made of fiber-reinforced plastic."

PRIZES FOR LONG CAST GENIUSES

Each year, the Institute of Design and Production in Precision Engineering invites mechanical engineering, vehicle construction and engine construction students to take part in a design competition in which they develop special machines. Inspired by the challenges of long distance mail delivery in the pandemic era, this year's program called for the creation of a small, but powerful, machine capable of flinging objects as far and accurately as possible. When throwing, the machine, which had to weigh just 500 grams and fit into a cube with an edge length of 150 millimeters, was required to remain stable. A small round chocolate ball served as a projectile, whereby competitors were free to choose any flavor they liked.

80 Graduates

50 MILLION EURO AND A PROGRAM FOR GRADUATES

Mobility in the future will be environmentally friendly, networked and automated, and the car of the future will be a robot all of which will require groundbreaking technologies – from completely new drive systems and components to innovative production processes and services. The objective of the Mobility of the Future Innovation Campus (ICM), in which the Karlsruhe Institute of Technology (KIT) and the University of Stuttgart are pooling their expertise, is to drive this process of transformation forward. One focus of the ICM is on the vision of digital production based on completely flexible production technology. Another point of focus is on additive processes that reduce drive system emissions, either by helping to reduce weight, assembly space, materials and energy or by combining the functions of different components.

The state of Baden-Württemberg is now carrying out a significant expansion of the ICM and will be providing another 50 million euro for this purpose over the next four years. 18 million will be spent on activities aimed at increasing the scientific dynamism and cutting-edge international research. Plans include a senior professorship in the field of merging IT and mechanical/vehicle engineering as well as six new junior professorships with junior research groups, and international excellence grants. Another 32 million euro have been set aside for innovative research, implementation and start-up projects. The main focus will be on digitalized mobility and production as well as emission-free mobility.

Up to 80 graduates from both universities are also expected to benefit from the funding under the ICM's so-called Covid-19 Graduate Program. To facilitate their entry into the labor market, which is currently difficult due to the Covid-19 pandemic, they may be temporarily employed at the universities, where they will work on projects and gain additional qualifications. At the same time, the program is intended to avert a shortage of skilled labor by using the current pandemic crisis as an opportunity to gain additional qualifications relating to the subject of mobility and the associated production processes, which will be a key topic for the future.

A COLLABORATION BETWEEN THE ARCHITECTURE CLUSTER OF EXCELLENCE AND ZÜBLIN

Stuttgart-based Ed. Züblin AG will be joining the "Integrative Design and Construction for Architecture" (IntCDC) Cluster of Excellence's "Industry Consortium" (IC). The IC is tasked with providing early carer support for doctoral students and postdocs, and provides both mentoring and guidance as well as reciprocal research exchanges. This facilitates the formation and longer-term consolidation of professional relationships, which in turn smooths the way to a career in industry. The aim is to ensure a direct knowledge transfer as well as a quick transfer of research findings into practice, and to test innovative solutions at pilot construction sites.

BIOINTELLIGENT HYDROGEN

12 MILLION

As one of three flagship projects, the H2BlackForest research center for a biointelligent hydrogen circular economy will receive around 12 million euro in funding under the RegioWIN 2030 initiative. Two University of Stuttgart Institutes, the Freudenstadt Campus and the Fraunhofer IPA are involved.

The H2BlackForest project comprises four subprojects, which will study the production of green hydrogen and the respective biointelligent circular economy in the Northern Black Forest region. The objective of the "FastCell" subproject is to make the customized production of fuel cell stacks ready for mass production using high-speed assembly technology. ReduCO_2 is using sustainable hydrogen-based technologies to accelerate CO_2 neutral production in the Northern Black Forest region. The WisFo subproject is about economic synergies information exchanges with SMEs, whilst researchers in the BioRoh subproject are collaborating with the Fraunhofer IGB to study how biotic raw materials, such as wood, could be used as a basis for sustainable and green hydrogen production.

SUSTAINABLE HYDROGEN PRODUCTION

Hydrogen-based synthetic fuels (PtX) are highly promising candidates in the search for carbon-neutral fuels, yet, they are only truly “green” if produced using renewable energies. In the “H2Mare” pilot project, which is funded by the German Federal Ministry of Education and Research (BMBF), a completely new type of system, which optimally integrates an electrolyzer and the processing plant for the direct conversion of the electrical current into synthetic fuels, will be integrated in an offshore wind turbine, whereby various offshore power-to-X methods are being studied. The University of Stuttgart’s Institutes of Energy Economics and the Rational Use of Energy (IER) and of Industrial Automation and Software Engineering (IAS) are involved in two subprojects and are being funded with a total of two million euro. They will be responsible for developing innovative algorithms for the intelligent operational management of the offshore PtX system and the associated process control technology.

RECTORATE TEAM REORGANIZED

The University of Stuttgart Senate re-elected the rectors on July 21, 2021 : Prof. Manfred Bischoff, head of the Institute for Structural Mechanics (IBB), will be prorector for research and junior academic staff, and Prof. Frank Gießelmann, head of the Institute of Physical Chemistry (IPC), will be prorector for teaching and further training. Prof. Silke Wieprecht, Professor at the Institute for Modeling Hydraulic and Environmental Systems (IWS) will take on the newly established Prorectorate for Diversity and International Affairs. The current Prorector for Knowledge and Technology Transfer, Prof. Peter Middendorf, Head of the Institute of Aircraft Design (IFB), was confirmed in office.

Dr. Simone Rehm, the current full-time Vice Chancellor for Information Technology (CIO), was confirmed in office for another six-year term at a meeting between the University Council and Senate on July 14, 2021 .


Prof. Manfred Bischoff


Dr. Simone Rehm


Prof. Silke Wieprecht


Prof. Peter Middendorf


Prof. Frank Gießelmann

20 YEARS OF ROBORACE

For 20 years, the “Roborace” competition has been challenging schoolchildren and students to solve new technical cybernetics tasks using a Lego construction set. The task set in this anniversary year was particularly tricky: to build a Formula 1-style robotic vehicle capable of driving around an unfamiliar race track independently and as rapidly as possible. Depending on the route section, gray gradients or side boundaries served as orientation points for the robot. Thirty-one teams participated in the competition, 15 of which got through to the final with their Lego robots, which – finally back to the present – was held on July 16.

Scan the QR code to see a video of the Roborace.

Photos: p. 6 Max Kovalenko, p. 7 DITF Denkendorf, University of Stuttgart/IKFF, p. 8 Amadeus Bramsiepe, KIT, p. 10 University of Stuttgart/Max Kovalenko, Frank Eppler, private, p. 11 University of Stuttgart/IST

3 QUESTIONS FOR

THE CREATORBOX2036 TEAM

The members of CreatorBox2036 – the name adopted by the student team of ARENA2036, a University of Stuttgart research platform for mobility and future production technologies – are involved in the development of groundbreaking technical solutions to everyday research challenges. For instance, the working students are helping with the automation of the Internet of Things in the ARENA2036. The CreatorBox2036 team are also implementing a project of their own; Fabian Geyer and Finn Jonas Peper explain what it entails.

What are you currently working on?

Our current project is the ARENA2036 Rapid Prototyping Service (ARPS), for which we need to develop a fully automated 3D printing system. Our objective is to make a user-friendly 3D printing service available to everyone in ARENA2036. Users can submit print jobs via a website, whereupon production on a free 3D printer will start fully automatically. We envisage automatic transportation of the finished prints from the printing platform to a warehouse via an autonomous transport vehicle. We are currently in the process of creating a 3D model, planning the mechatronic systems and programming the control system.

What is the greatest challenge in all of this?

We often encounter maintenance issues or defects. For example, our 3D printer is fitted with a small extruder with a diameter of just 0.4 millimeters through which the liquid or semi-liquid material passes for days on end. This extruder can get clogged up if the temperature setting is incorrect or if the run time is particularly long, in which case we have to disassemble the whole 3D printer and repair the component in question. We are currently working on data collection and early detection with a view to solving this issue in order to automate and stabilize the process.

What's so special about the CreatorBox2036?

During your university studies, you often find yourself surrounded by people studying exactly the same thing as you. In contrast, students with different skill sets studying anything from electrical and information engineering to technical cybernetics, mechanical engineering, aerospace engineering or autonomous systems are brought together in the CreatorBox2036. We enjoy sharing our ideas and knowledge among ourselves and are delighted about being able to turn our hobby into a job. We work in an extremely independent manner and enjoy a lot of freedom to express ourselves.

Scan the QR code to see a video about the new CreatorBox2036 3D printing system.

Photo: ARENA2036 e.V.

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Pushing digitalization

TEXT: Andrea Mayer-Grenu
PHOTOS: Sven Cichowicz

Software and data expert Prof. Bernhard Mitschang is combining information technology and production, whereby he is counting on young researchers and team spirit.

Prof. Bernhard Mitschang

"The Internet still didn't exist in its current form back then; apps were a foreign word, and the technology was still in the Stone Age."

The traditional areas in which databases and information systems were used just 20 years ago included banks and insurance companies, the business world, technology and science. "The Internet," as Bernhard Mitschang, who has held the Chair of Databases and Information Systems at the University of Stuttgart's Institute for Parallel and Distributed Systems since 1998, remembers, "still didn't exist in its current form back then; apps were a foreign word, and the technology was still in the Stone Age." The turning point came with the Internet of Things (IoT). "The Internet, and especially the IoT have brought about a radical convergence between manufacturing and information technology," Mitschang explains adding that this is reflected in an almost complete interconnectivity and a comprehensive digital data production and provision system. "The many social media applications are examples of this as are the digital, real-time factory, so-called 'advanced manufacturing technology,' everything that falls within the sphere of Industry 4.0, and cyber-physical IT systems."

Mitschang himself played a role in this development at an early stage. Shortly after his appointment at the University of Stuttgart in 1998, he contacted Prof. Engelbert Westkämper, the then spokesman for the Collaborative Research Center SFB 467 (Adaptable Corporate Structures for Highly Variable Series Production) and one of the pioneers in the field of advanced manufacturing. "I've been collaborating with mechanical engineers ever since," says Mitschang. He was also involved in the "Graduate School of Excellence Advanced Manufacturing Engineering" (GSaME), one of the University of Stuttgart's first two excellence projects, right from the start and has been its spokesperson since 2014.

"DATA SCIENCE" DEGREE PROGRAM LAUNCHED

The Chair's research focus has changed in response to the digital transformation in industry. "We are currently working on issues that have to do with data provision, data management and data analysis with a view to developing and supporting the applications of digitalization. The relevant buzzwords include Big Data, Data Mining, Machine Learning and also Data Science." Mitschang and his team are taking a twin-tracked approach to tackling the challenges that underlie these buzzwords. On the one hand, the Chair has adapted the range of degree courses on offer and established the "Data Science", bachelor's degree program – a rarity in Germany. On the other, the research focus has been adapted to enable researchers to provide the best possible answers to the questions of Big Data and data analysis in their respective industrial application contexts.

The "ICT Platform for Production" junior research group at GSaME, which has been headed up by Dr. Peter Reimann since 2017, is one example of this. The group focuses on an information and communication solution that not only integrates production processes, →

→ but also the heterogeneous, distributed information systems throughout the company as well as such things as mobile devices. The projects are defined in collaboration with industry partners such as Daimler, Festo, Trumpf or Mann+Hummel and supported via the individualized qualification program. They are then implemented in compliance with the GSaME's quality standards. "We are extremely careful to ensure that rather than simply being chosen and implemented on a 'let's do it' basis, all work carried out is scientifically relevant," Reimann emphasizes.

ICT PLATFORM FOR THE ENTIRE PRODUCT LIFE CYCLE

At an early stage, the group developed the "Stuttgart IT Architecture for Manufacturing" (SITAM), which enables companies to acquire, manage and analyze data. The data analysis functions in the SITAM are currently being expanded. Implementing data analysis technologies across the entire product lifecycle rather than just in certain individual production phases is the aim of industrial analytics. "This gives us a better understanding of and enables us to optimize such things as products, entire factories and individual machines," as Reimann explains.

MAKING SENSE OF THE DATA LAKE

The basis for such holistic analyses are so-called data lakes, which are highly scalable databases into which the raw data generated along the value creation chain flows, making data lakes a very flexible basis for data analysis. However, as Doctoral Researcher Rebecca Eichler explains, the problem is that "companies often don't even know what data their 'data lakes' contain, as it is inadequately described." Among other things, the systematic storage and management of the enormous data volumes to create added value requires one to document what data exists, what it describes, its quality and origin, and who is permitted to access it. So, data management relies on so-called metadata, i.e., data about the data. It is precisely this metadata management to which Eichler is devoting her doctoral project "MetaMan" (under the supervision of Dr. Holger Schwarz), which she and Bosch are working on together.

The relevant question goes beyond data lakes to take in the entire corporation. "Until now," she explains, "metadata management has been focused on individual sub-processes or corporate departments. What we are trying to do in our project is to develop techniques and concepts for designing a metadata management system for the entire corporate structure so that, for example, data can be made available across departments." This is inspired by existing inter-company data marketplaces. One can think of them as platforms, →

Dr. Peter Reimann

"Carrying out data analytics throughout the product lifecycle, gives us a better understanding of and enables us to optimize such things as products, entire factories and individual machines."

REBECCA EICHLER

"Companies often don't even know what data their 'data lakes' contain, as it is inadequately described."

Dr. Pascal Hirmer

"Industry 4.0 presents companies, especially small and medium-sized enterprises, with a huge challenge."

→ which use metadata to enable users to find, understand and access data as well as to upload their own data.

Very often when this concept is transferred to the internal corporate environment, more sensitive data is traded on the data market. "This means that issues of transparency and compliance take on a whole different level of significance," Eichler explains.

CONSTRUCTION KIT FOR THE INDUSTRIAL SECTOR

Very specific proposals for the manufacturing industry were developed by the flagship "Industrial Communications for Factories (IC4F)" project in which 14 partners collaborated having received 13 million euro in funding from the German Federal Ministry for Economic Affairs and Energy (BMWi). "That's a lot for a computer science project," says Dr. Pascal Hirmer, and goes on to explain why: "Industry 4.0 presents companies, especially small and medium-sized enterprises, with a huge challenge. It involves a plethora of new technologies, heterogeneous infrastructures, and compliance with data protection legislation, on top of which, the entire thing is both time-consuming and expensive. That's why," he continues, "we developed a reference architecture in the IC4F project, which is called iRefA (industrial Reference Architecture), and which companies can use to construct secure, robust and real-time communications solutions."

The iRefA works like a set of Lego blocks comprised of hardware and software components, network technologies, security modules and more. "Companies specify their needs in requirements workshops, and our platform suggests semi-automated building blocks that best fit the desired application. This enables the project staff to decide between the best alternatives." The longer-term plan is to standardize the iRefA as a DIN specification.

DIGITALIZATION CONTINUES TO MAKE PROGRESS

As a flagship project, IC4F will spawn further research projects, which, as Mitschang explains, is important because, among other things, digitalization will continue to advance within the industrial sector. Expertise in this area is still lacking, especially in the SME sector. "That's why we need to push the digitalization agenda and train talented people, who will go on to integrate the digital transformation into industrial applications to optimize operations." ⇥

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Industry 4.0:

The biological transformation is coming

TEXT: Birgit Spaeth

Along with the digital transformation a biological transformation is also taking place, which will result in the production of an increasing number of so-called biointelligent systems.

Organic material: malleable building materials can be made from the rapidly growing fungal mycelium.

Prof. Arnd G. Heyer

"The construction material is lightweight, has good insulating properties and is extremely malleable."

The optimization of industrial production processes has long been inspired by nature. As Prof. Thomas Bauernhansl, head of the Institute of Industrial Manufacturing and Management (IFF), explains: "A sustainable biological transformation of industrial value creation is crucially important both for society and the economy and can no longer be postponed. "It could solve a lot of problems caused by such things as demographic change, globalization, the individualization of society, climate change and the increasing scarcity of natural resources throughout the world." On Bauernhansl's initiative, numerous institutes at the University of Stuttgart as well as the Fraunhofer Institutes IPA and IGB, the University of Hohenheim and other research institutions around Stuttgart have joined forces to found the Biointelligence Competence Center. But what exactly does biointelligence mean?

NATURE AND TECHNOLOGY – FROM INSPIRATION TO INTERACTION

The process of biological transformation, the final stage of which results in biointelligence, can be divided into three modes of development: inspiration, integration and interaction. First, inspiration enables the application of biological phenomena that have evolved over millions of years to value-creation systems. Companies use this approach to develop new materials and structures (e.g., lightweight construction), functionalities (e.g., biomechanics), and organizational and collaborative solutions (e.g., swarm intelligence). This field of research is already widely known as bionics.

The integration mode involves applying our knowledge of nature to actually integrate biological systems into production systems, for example by replacing chemical processes with biological alternatives or using microorganisms to recover rare earths from magnets or to produce hydrogen from garbage. Another example is the use of biological raw materials in architecture.

GROWING STRUCTURES FOR THE CONSTRUCTION INDUSTRY

Prof. Martin Ostermann, head of the University of Stuttgart's Institute for Building Construction (IBK), for example, is researching the suitability of fungal mycelium for use as a construction material. "The goal," Ostermann explains, "is to use this organic material in structural engineering applications to develop an alternative to traditional inorganic construction materials." His team is collaborating with a research group led by Prof. Arnd G. Heyer of the Institute of Biomaterials and Biomolecular Systems (IBBS).

When combined with waste from the construction and agricultural industries, mycelium, a rapidly-growing organic material, forms a plastic. "The fine fungal strands," as the sustainability expert goes on to say, "bind loose, particulate organic fibrous materials into solid molded pieces that can be used as construction materials when dry. It is lightweight, has good insulating properties and is extremely malleable." Mycelium →

→ grows within a few days and requires no energy-intensive manufacturing processes. It is fully compostable and can be fed back into biological cycles as a nutrient – in other words it is a bioinspired and biointegrated system.

HYDROGEN FROM THE GARBAGE CAN

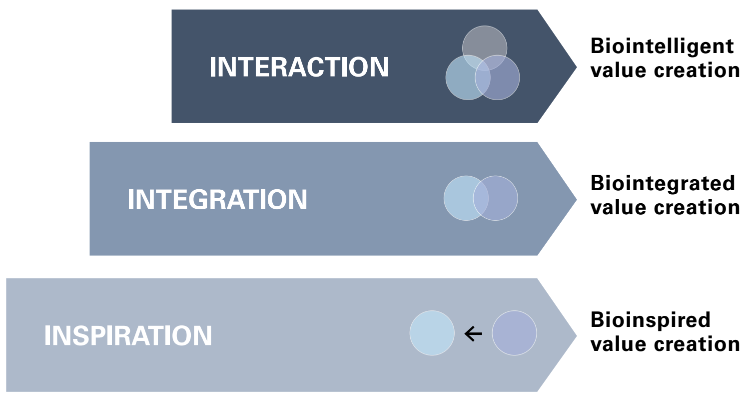
Another project at the University of Stuttgart's Institute for Energy Efficiency in Production (EEP) is taking things a step further: it involves the generation of energy that not only does no harm to the climate, but actually benefits it. As is well known, hydrogen produced by electrolysis using electrical energy can be converted into usable electrical or thermal energy in fuel cells. The residual energy in many waste materials can also be recovered in the form of hydrogen. The interesting thing about the special process, which was developed and analyzed at the EEP and the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) is that capturing and storing the CO_2, which is produced as a by-product, not only makes the conversion process climate neutral, but even has a positive effect on the climate.

"The so-called HyBECCS processes (Hydrogen Bioenergy with Carbon Capture and Storage), will be able to offset unavoidable greenhouse gas emissions in the future," says project manager Johannes Full: "This increases the flexibility and efficiency of our energy system whilst actively counteracting climate change. Applying advanced IT systems for flexible and intelligent process control could increase the application potential even more. Then it will be possible to use biointelligent HyBECCS processes to solve significant societal and environmental problems."

So this comprehensive interaction between technical, informational and biological systems represents the third stage of the biological transformation. It will gradually lead to new, self-sufficient production technologies and structures, which will then constitute biointelligence.

A VISION OF A TECHNOLOGY-BASED DEMAND ECONOMY

Biointelligent value creation will facilitate progress in many areas ranging from personalized healthcare to the intelligent organization of transportation and production systems to the decentralized production of consumer goods and food from renewable regional raw and recycled materials. →



The biological transformation of industrial value creation

Climate Positive Impacts: The energy generated by waste incineration can be converted into various products including hydrogen.

Prof. Thomas Bauernhansl

„An advanced economic system is developing here that takes account of the physical constraints of our planet."

→ A sustainable, technology-based demand economy could emerge from a merger between biology, (production) engineering, and data processing. "An advanced economic system is developing here that takes account of the physical constraints of our planet," says Thomas Bauernhansl, founding executive director of the Biointelligence Competence Center. He is convinced that: "we are creating new space for innovation across many disciplines in this way with enormous potential, including economic potential." ⇥

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Photos: University of Stuttgart/IBK, Stastny/Shutterstock

WOUND LIGHTNESS

TEXT: Andrea Mayer-Grenu

“How will we live together?” This is the central question for this year’s Biennale Architectura in Venice. The University of Stuttgart’s IntCDC Cluster of Excellence has responded to it with radically new fiber construction methods.

Walk-in installation: “Maison Fibre” at the Biennale Architectura 2021 in Venice

Ethereal architecture in the form of a transparent multi-story and feather-light web of fiber: “the Maison Fibre” almost seems to float. Presented by the Institute for Computational Design and Construction (ICD) and the Institute of Building Structures and Structural Design (ITKE) as part of the Arsenal of the 2021 Biennale Architectura in Venice, the Maison Fibre gives visitors the spatial experience and leaves them with the structural impression of a “building” whose structural elements can be made from just a few kilograms of material, sometimes even directly on site.

Both are urgently needed to get on top of the major environmental and sociological challenges involved in construction work because, at this moment, it is common practice to purchase ease of construction at the cost of additional material requirements: hardly any other human activity consumes more resources and releases more emissions than construction work, so new conceptual paradigms are urgently needed. “Our entry to the Biennale calls prevailing material-intensive construction methods into question and replaces it with a fiber-based architecture that uses only a fraction of the building materials and opens up completely new design possibilities,” says architect Prof. Achim Menges, the spokesperson for the University of Stuttgart’s Integrative Computer-Based Design and Construction for Architecture Cluster of Excellence (IntCDC) and head of the ICD. “Compared to Le Corbusier’s Maison Dom-Ino, a highly influential model for 20th-century architecture, the Maison Fibre’s weight is reduced by a factor of fifty, thus opening the doors to a new material culture.” Not only will this encompass architecture, but also the related ecological (materials and energy), economic (value creation chains and knowledge production), technical (digital technologies and robotics), and sociocultural issues.

Prof. Achim Menges

“Our entry calls prevailing material-intensive construction methods into question.”

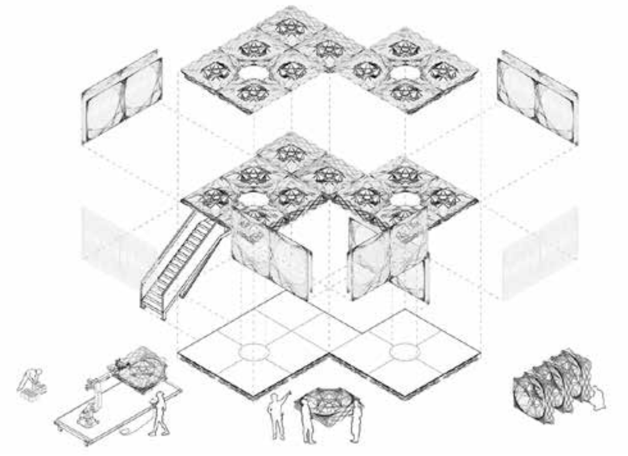
THE WORLD’S FIRST MULTISTORY FIBER STRUCTURE

This paradigm shift was inspired by nature: nearly every biological load-bearing structure is constructed from fibers whose orientation, direction and density are matched precisely to the forces acting upon them. This makes them simultaneously differentiated, functional and resource-efficient. Research into the biomimetic principle of “less material through more form” has been conducted at the University of Stuttgart for many years and has been showcased, among other things, in several exhibition pavilions that have received worldwide attention. For the first time, the researchers are now applying their acquired experience with robotically manufactured fiber composite structures to load-bearing multi-story ceiling and wall construction elements. “The Maison Fibre,” as Menges emphasizes, “is the first multi-story fiber structure of its kind. It is based on an extremely lightweight, digital construction system made up entirely of fibers. Just a few years ago, it could neither have been designed nor manufactured.”

FROM THE INDUSTRIAL INTO THE ARCHITECTURAL SECTOR

The entire structure consists of so-called rovings, i.e., bundles of endless, unidirectional fibers. A robotic winding process with industrial roots, which was developed by →

Larger than life guest appearance: individual components of the installation being transported to Venice



A continuous process: design development sketches

Supporting structures: the researchers stretch the fibers freely over a rack.

→ the two institutes, is used to manufacture the load-bearing wall and ceiling elements. In industrial settings, this “filament winding” method is used to produce elongated, rotationally symmetrical components such as pipes. The process involves using a winding machine to deposit fibers on a rotating cylindrical core. However, as Christoph Zechmeister,a doctoral student at the ICD, explains, applying this method to architecture raises a problem: “the shape of the component relates directly to the shape of the core. This is fine in a low-cost mass production context, but we need more flexibility in architecture, which is why we already wondered whether the core could simply be left out of an earlier fiber pavilion.” The idea worked, so the researchers at ICD and ITKE now stretch the fibers freely across a framework. “The form-giving parameters are the shape of the frame as well as the fibers themselves,” Zechmeister explains. “The first fibers form the support structure for the subsequent ones.” The robot-assisted winding process is fully automated. “We only intervene to change the material or operate the robot.”

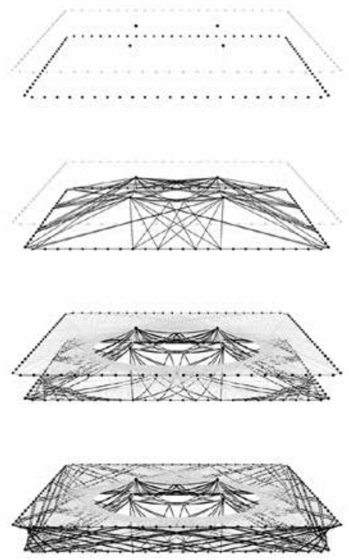
Not only does the continuous molding process allow for a large degree of design freedom, but it also ensures an extremely low material consumption level, whereby the researchers take advantage of the so-called anisotropy phenomenon, i.e., the fact that fibers have different properties in different directions, which means that they can be matched to the respective requirements in a very differentiated manner. For example, the comparatively heavy carbon fibers are only used where they are really needed for load transference purposes, and the fiber thickness also depends on the respective stress loads. The production of a load-bearing floor element, for example, only requires a material volume of less than two percent of the component volume.

An expensive and time-consuming journey: but the development team’s goal is to create the framework conditions for on-site production.

FACILITATING COMPLETE ON-SITE PRODUCTION

The sparing use of materials pays off: the fiber structure weighs many times less than a comparable concrete structure – the load-bearing fiber structure of the floor elements on the upper floor weighs just 9.9 kg/m². The wall elements are much lighter still, which, as Prof. Jan Knippers, one of the directors of the IntCDC cluster of excellence and head of the ITKE explains, has several benefits: “In future, the process will make it possible to do all the manufacturing on site without creating significant levels of noise or waste. And the extremely low weight makes installation much easier, because no heavy transport equipment, scaffolding or lifting devices are needed.” This not only applies to the initial erection process, but also to any future extensions or conversions. So, architecture built using this construction method will remain adaptable and flexible over the long term.

The Maison Fibre still uses the currently available fiber and resin systems, but the concept can be used with a wide range of materials, and the researchers are hoping that the range of materials will expand considerably in the near future. “Among other things,” as Menges and Knippers reveal, “we are currently studying mineral fiber systems that can withstand extreme temperature loads, and natural fibers that regenerate within a one-year cycle.” ⇥



Continuous construction: the first fibers form the support structures for the subsequent ones.

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Photos: University of Stuttgart, ICD/ITKE/IntCDC, Filippo Ferrarese

Photo: Blesius, Hameln, T. Franz

WHO, IF NOT US?

GUEST ARTICLE: Dr. Eberhard Veit

Eberhard Veit, an expert in innovation, believes that a radical change in corporate management is required if companies are to remain at the forefront of advanced manufacturing at the international level. He outlines the steps needed to achieve this in the following forschung leben guest article.

When I was the CEO of Festo many years ago, I was able to observe how quickly people accepted the impact of digitalization in their everyday private lives. I would meet consumers who were enthusiastically embracing the latest technologies and services. At the same time though, it was totally frustrating to observe the industrial sector's reluctance to embrace the newly emerging technologies for advanced value creation thereby helping to shape the change. Consequently, leadership style and decision-making behaviors needed to be radically overhauled and managers need to practice "ambidextrous leadership", by which I mean that optimizing existing systems must be promoted just as much as developing new ones.

What this means for industry and advanced manufacturing (AM) is that, in addition to the focused further development of our manufacturing sector using central/decentralized intelligence, robotics, human-machine interfaces, advanced logistics systems, instrumentation, motion control, architecture models and platforms, intelligent components and sub-systems, we also have to address the "advanced" aspect though the use or application of M2M communications, cloud computing, machine learning, cyber security, smart components, visualization and simulation as well as artificial and augmented reality.

The success of our industries is critically dependent not only on their acceptance of new technologies, but also on their ability to monetize them. The objective is to actively boost the "evolutionary revolution" in terms of the technology as well as the radical change in leadership within organizations. →

→ One needs to fully adopt a "4C culture" if one is to become an advanced manufacturing winner on a global scale, whereby the four Cs stand for culture, content, taking a chance, and starting the change. In addition to technology, therefore, we need to establish a culture in which people are encouraged to play an active role in shaping change in a spirit of courage and risk readiness. Achieving our objective of being "best of class in advanced manufacturing" will not only require managers to embrace a bold, long-term vision of advanced value creation, but the entire organization must also embrace the notion of ambidextrous leadership, which is why I came up with the acronym **"SPRINT"** to outline my formula for the necessary internal change:

S PIRIT/SPEED
P ARTICIPATION
R ELY
I NSPIRATION
N EED
T RUST

novel ideas may sound simple and familiar, but do we really do it in Germany? Not really, no! It will change the way companies operate at all levels, so CEOs will have to hold the entire organization together under a banner of urgency and change. They must embody the spirit of change and exemplify the necessary speed. They need to inculcate a culture of open communications and active participation and encourage the entire workforce to act in unison and to learn to embrace new digital systems for advanced manufacturing. One of the CEO's tasks is to inspire people throughout the organization to align their thought processes and actions to novel digital processes and methods, to understand how to use the new tools, and to recognize the need for transformation. And finally, the change process requires people to have faith in the new technologies and approaches. →

DR. EBERHARD VEIT

"Whilst technology will account for 50 percent of the success, the other 50 percent will be based on leadership, training and lifelong learning."

Eberhard Veit holds a doctorate in engineering and studied at the University of Stuttgart, among other places. He joined the Festo AG Management Board in 1997 and served as its CEO from 2008 to 2016. He currently plays an active role in his own company 4.0-Veit. He has been a member of Robert Bosch Industrietreuhand KG since 2019, where he is due to become one of the two general partners starting in 2022.

→ The transformation process will only succeed on the basis of these principles. These recommendations in turn build on five key elements that I group together under the term "**AGILE**," which is my second formula.

A RCHITECTURE-BASED
G ENERAL BUSINESS MODELS
I NNOVATION
L EARNING
E DUCATION

ARCHITECTURE: flexible, architecture-based products and components working together in a collaborative and networked manner to form systems and sub-systems as well as systems that can be integrated intuitively. Important elements include a consistent plug-and-produce concept of central/decentralized intelligence, robotics, human-machine interfaces, advanced logistics systems, instrumentation, motion controls, architectural models and platforms, intelligent components and sub-systems.

GENERAL BUSINESS MODELS: new ways of making money will result from new ways of organizing operations. AM requires cross-company networks and more effective collaboration. The desired digital value creation process is created on the basis of decentralized and centralized production topographies with flexible on-demand supply, the use of artificial intelligence for predictive maintenance and a data-driven control and inspection system. Basically, a tailor-made suit is created from standard systems as a digital twin that has been planned and implemented.

INNOVATION: European companies need to produce better and more innovative products and systems, as their development and production processes are generally much more expensive: we can and must be better by at least as much as we are more expensive.

LEARNING: we need to adopt a positive attitude towards lifelong learning and develop a willingness to acquire new skills on a continuous basis, especially now and particularly in areas in which we have always been strong. It will only prove possible to implement AM successfully if this factor undergoes a significant expansion.

EDUCATION: it takes a commitment to invest in people's knowledge, to qualify them and to develop their skills through cutting-edge training programs. State and corporate investments in education promise the highest return on invested capital in terms of tax revenue, profit and prosperity.

So, do we need to employ completely new people and bring in totally new skills to become fit for the future? No, the most promising formula is a judicial mix of new talent and experienced, long-term employees. Success will largely be gained through training and education. In 2020, 27.4 billion euro were spent on research into new technologies in Germany, but only 8.2 billion euro were invested in the education system. I am convinced that whilst technology will account for 50 percent of the success, the other 50 percent will be based on leadership, training and lifelong learning. This requires a tangible cultural transformation.

It is worth emphasizing that agile, ambidextrous leadership will be the key driver on the way into a new era of confidence in the digital sector and the implementation of AM because companies will only achieve long-term success if we all take the transitional era seriously and, against the backdrop of today's core business, focus intently on the leap into the digital future. ⇥

CONCENTRATED INNOVATIVE CAPACITY

PHOTOS: Max Kovalenko

Industrial manufacturing must evolve to meet the challenges of the future. The Stuttgart Center for Manufacturing Technologies (PZS) is making some important contributions toward this goal.

The Stuttgart Center for Manufacturing Technologies (PZS) has been combining the individual strengths of twelve Institutes from four faculties with a total of 400 research staff since 2017. As Prof. Mathias Liewald, head of the University of Stuttgart's Institute for Metal Forming Technology (IFU) and spokesman for the PZS explains: "Due to the research they carry out in the field of production and information technology, PZS Institutes have had a visible profile for years. Our scientific work is focused on the technological processes of various manufacturing methods, production flows and value creation chains. Our objective," he continues, "is to work on future technologies and to take part in corresponding global developments that will eventually be adopted by companies within five to ten years." This objective, he says, is reflected in three fields of research: the optimization of value creation chains in a production setting in the context of resilient and circular value creation: the use of artificial intelligence (AI) methods in production, and finally sustainability, resource efficiency and climate neutrality.

THE ROLE OF PEOPLE IN LOGISTICS PROCESSES

For example, two projects relating to inter-logistics and intralogistics, i.e., the global movement of goods between companies or within a company respectively, are focused on the role of people in the relevant logistics processes, because due to their cognitive abilities and high degree of flexibility, especially when it comes to picking goods, humans are indispensable in these processes. The "FlexLight" project is aimed at achieving a step-by-step →

Combining strengths: Prof. Mathias Liewald is the spokesman for the Stuttgart Center for Production Technology (PZS).

→ improvement of manual picking performance through the use of a flexible pick-by-light system whereby rather than working with a packing list, the desired goods are visually displayed to the picker directly at the storage location. Conventional picking methods are rigid and, by definition, inflexible. The new approach, on the other hand, can independently expand itself and the system can be designed for specific applications. The project objective is to achieve an easy integration or adaptation of the picking method in changing environments. ThingOS GmbH, a spin-off of the University of Stuttgart, is our research partner in this project.

The "S³ - Safety Sensor Technology for Service Robots" project is our second example from the field of production logistics and involves research being carried out by the Institute of Mechanical Handling and Logistics (IFT) into the development of safe 3D environment sensor technology for use in mobile robots. Our project partners are Alexander Thamm GmbH, Pilz GmbH & Co. KG, the Fraunhofer Institute for Manufacturing Engineering and Automation IPA, and the BruderhausDiakonie of the Gustav Werner Foundation, and Haus am Berg. The aim is to develop sensor technology that is capable of reliably monitoring the environment in three dimensions, distinguishing between people and objects, and detecting irregularities.

The Institute for Manufacturing Technologies of Ceramic Components and Composites (IFKB) has also been a partner of the PZS since its foundation and collaborates with us on such things as the "KeraBear" project, which is funded by the state of Baden-Württemberg. The project was developed among a network of research partners all working in the field of production technology including Furtwangen University and the Fraunhofer Institute for Mechanics of Materials IWM in Freiburg. The goal of the project partners is to develop an innovative coating system for friction bearings to replace the materials commonly used today, because whilst these perform very well, they contain tungsten, cobalt and nickel – all heavy metals, which are considered problematic from an environmental and political perspective. Our current task is to qualify relatively new and harmless carbide and oxide ceramic materials for use in friction bearings. The coating process we use, which was developed at the IFKB, is known as high-speed suspension flame spraying.

SUSTAINABLE PRODUCTION PROCESSES

The Institute of Laser Technologies (IFSW) is also involved in the PZS network and deals specifically with potential future laser applications for things such as a machining tool, whereby they opt for a holistic approach developing and researching laser-based manufacturing processes, suitable beam sources and the necessary plant and system engineering processes.

"Two other key research fields have recently been established at the University of Stuttgart in collaboration with the Fraunhofer Society," says Liewald, "both of which relate directly to future production technologies: one concerns the sustainability and resource efficiency of production processes, whilst the other involves the broad field →

80

Various approaches are being investigated by over 80 partners to specifically manage the industry's electricity needs without having a negative impact on product quality or delivery schedules.

Rob-aKademI: the objective of this research project is to simplify assembly task programming.

Progress in laser technology: the industrial TRUMPF 3-D laser cutting system used at the IFSW

→ of AI in production technology. We at the PZS benefit greatly from the work being carried by researchers in both fields with their specific expertise and networks."

The Institute for Energy Efficiency in Production (EEP), for example, coordinates the "Synergy" Copernicus project, which is part of the German Federal Ministry of Education and Research's (BMBF) largest energy research initiative. The objective of the project is to adapt industrial energy demand to the increasingly volatile supply of renewable energy. Various approaches are being investigated by over 80 partners to specifically manage the industry's electricity needs without having a negative impact on product quality or delivery schedules. Thus far, a total flexibility capacity in the order of three nuclear power plant capacities has been identified and developed for German industry.

Increasing energy efficiency is a key pillar in the energy transition. The EEP collaborated in the "ACE - Asset Class Energy Efficiency" project with the Klimaschutz- und Energieagentur Baden-Württemberg GmbH (Baden-Württemberg Climate Protection and Energy Agency) and the German Industry Initiative for Energy Efficiency (DENEFF) to find out how investments in industrial energy efficiency could be financed more easily, because within companies such investments are always in competition with strategic investments in actual value creation. The requirements of the financial sector, energy service providers and manufacturers were analyzed in the course of the project. The project findings are set out in a project planning guide, which the German Federal Ministry for Economic Affairs and Energy (BMWi) will be able to expand upon to increase industrial energy efficiency.

USING ARTIFICIAL INTELLIGENCE TO PROGRAM ROBOTS

A collaboration between the Fraunhofer IPA and the Institute of Industrial Manufacturing and Management (IFF) is an example of a PZS project involving AI: the "Rob-aKademI" project, which has just recently been completed, looked into the expertise required to program a robot to automate industrial handling or assembly processes. "Machine learning initiatives such as these will become much more important in production engineering in the near future," says Liewald. The robot can be programed with no manual intervention by combining a powerful physics simulation with so-called "Reinforced →

→ Learning", which is a special case of machine learning. The robot can even perform complex, force-controlled assembly operations "itself". This methodology is currently being studied and tested in practice in collaboration with industry partners based on switch assembly and circuit board component installation processes.

OPTIMIZING THE FORGING PROCESS

The Institute for Metal Forming Technology (IFU), the Institute of Industrial Automation and Software Engineering (IAS) and various industrial partners recently completed another project involving AI, the objective of which was to design a forging process of exemplary efficiency. Forging involves heating solid materials to high temperatures and then pressing them into the desired shape in a die or mold. The microstructure of the material can be adjusted by means of controlled cooling, for example, to achieve the desired strength of the component. Numerical simulations are usually used to calculate such forging processes in order to subsequently qualify them for a real-world series production ramp-up with no loss of time or test phases. Unfortunately, simulations and reality often diverge: in extreme cases, the simulation indicates that the component will fail, whereas it is not so bad in reality or vice versa. "Therefore," as Liewald explains, "we were faced with the scientific challenge of studying production and simulation data to gain specific insights in order to be able to use a neural network to compensate for fluctuating process conditions in terms of the expected component quality."

An IFU team is now transferring this approach to series production start-up processes in cold forming, which is used to manufacture such things as gears or hollow shafts for lightweight construction. "In this project," says Liewald, "the production start-up phase is, as it were, moved to a steady state as efficiently as possible, the objective being to largely eliminate so-called startup scrap". This significantly reduces the effort required – and therefore the costs – especially for small batches. ⇥ mv

Prof. Mathias Liewald

"Machine learning initiatives such as these will become much more important in production engineering in the near future."

Photos: Max Kovalenko, University of Stuttgart/ISW, Fraunhofer IPA

THE TWELVE PZS INSTITUTES:

- Institute of Electrical Energy Conversion (IEW)
- Institute for Energy Efficiency in Production (EEP)
- Institute for Manufacturing Technologies of Ceramic Components and Composites (IFKB)
- Institute of Aircraft Design (IFB)
- Institute of Mechanical Handling and Logistics (IFT)
- Institute of Industrial Manufacturing and Management (IFF)
- Institute of Parallel and Distributed Systems (IPVS)
- Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW)
- Institute of Laser Technologies (IFSW)
- Institute of Applied Optics (ITO)
- Institute for Metal Forming Technology (IFU)
- Institute for Machine Tools (IfW)

A glance at the work carried out at the ISW: With the aid of a software program, the aim is for the robot to learn to accurately locate and grasp an object, such as a cable.

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Improving simulations

TEXT: Michael Vogel
PHOTOS: Max Kovalenko

A research team at the University of Stuttgart wants to optimize materials data for use in material forming process models. Their approach combines simulations with artificial intelligence and requires an enormous amount of computing power.

Simulation and reality converge in sheet metal forming: that is the goal of a collaboration between the IFU and the HLRS.

Enormous computing power: the research group has requested computing time at the Gauss Centre for Supercomputing.

2 Billion

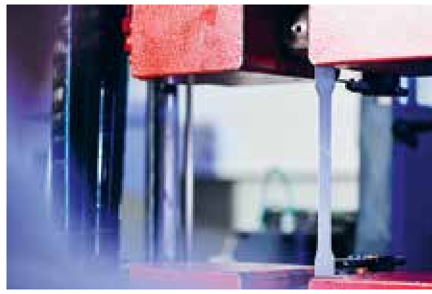
The neural network has to perform two billion simulations to obtain 1000 measured values per sample.

Sheet metal forming is crucial to the automotive industry and is used to form such things as doors, hoods and fenders. Often, the geometries of the finished components are extremely complex. Simulations have been used for many years to facilitate the design of the forming tools required for this purpose and can, for example, reduce the cost and effort of post-processing. Yet the fact that sheet metal forming simulations and reality only converge to a limited extent is a problem, not least because of the high cost of the machine tools, which can quickly run into seven figures in the automotive industry – per machine tool! Accurate materials data is required to further reduce the discrepancy between simulations and reality. A team headed up by Dr. Celalettin Karadogan of the Institute for Metal Forming Technology (IFU) and Dennis Hoppe of the High Performance Computing Center Stuttgart (HLRS) is currently collaborating on an approach aimed at determining such data with a high degree of accuracy for the material models used in the simulations with as small an experimental effort and time expenditure as possible.

“These days,” Karadogan explains, “we use established materials models and simulations based on these models to calculate forming processes. Nevertheless,” he continues, “the simulated and physical materials differ from one another because, whilst we can empirically determine physical variables, such as the yield stress, for the material models, the measured data cannot be transferred directly into the computational model in the form of variables."

Karadogan’s team now wants to use AI – or more precisely, a neural network – to perform this transfer operation. “During the material tests,” he explains, “we project a pattern onto our samples, which we record along with the measured forces.” Both the pattern image data and the measured forces are fed into a neural network, which is then tasked with searching out the mathematical variables of the model against this background. The team numerically modifies the mathematical variables to cover as many materials as possible. “Rather than just the two measured values per test sample used in previous approaches,” says Karadogan by way of clarification, “this approach gives us 1000 measured values per sample.”

To achieve this, the neural network has to perform two billion simulations. As this is far more than can be achieved using a conventional computer, Karadogan’s group has requested 100 million core hours of computing time on the HLRS’s supercomputer Hawk, via the Gauss Centre for Supercomputing. A core is one of the supercomputer’s processing units. The researchers are now collaborating with Hoppe, Head of Service Management & Business Processes at the HLRS, and his team to combine simulations and AI – a combination that is being used increasingly in data science and is being researched intensively at the HLRS under the auspices of the CATALYST project. In a pilot project in which five million simulations served as training data for the neural network, the project participants have already succeeded in demonstrating that the approach works in principle. ⇥



Groundbreaking AI: there are major differences between the behavior of the simulated and the physical material. A neural network is to remedy this situation.

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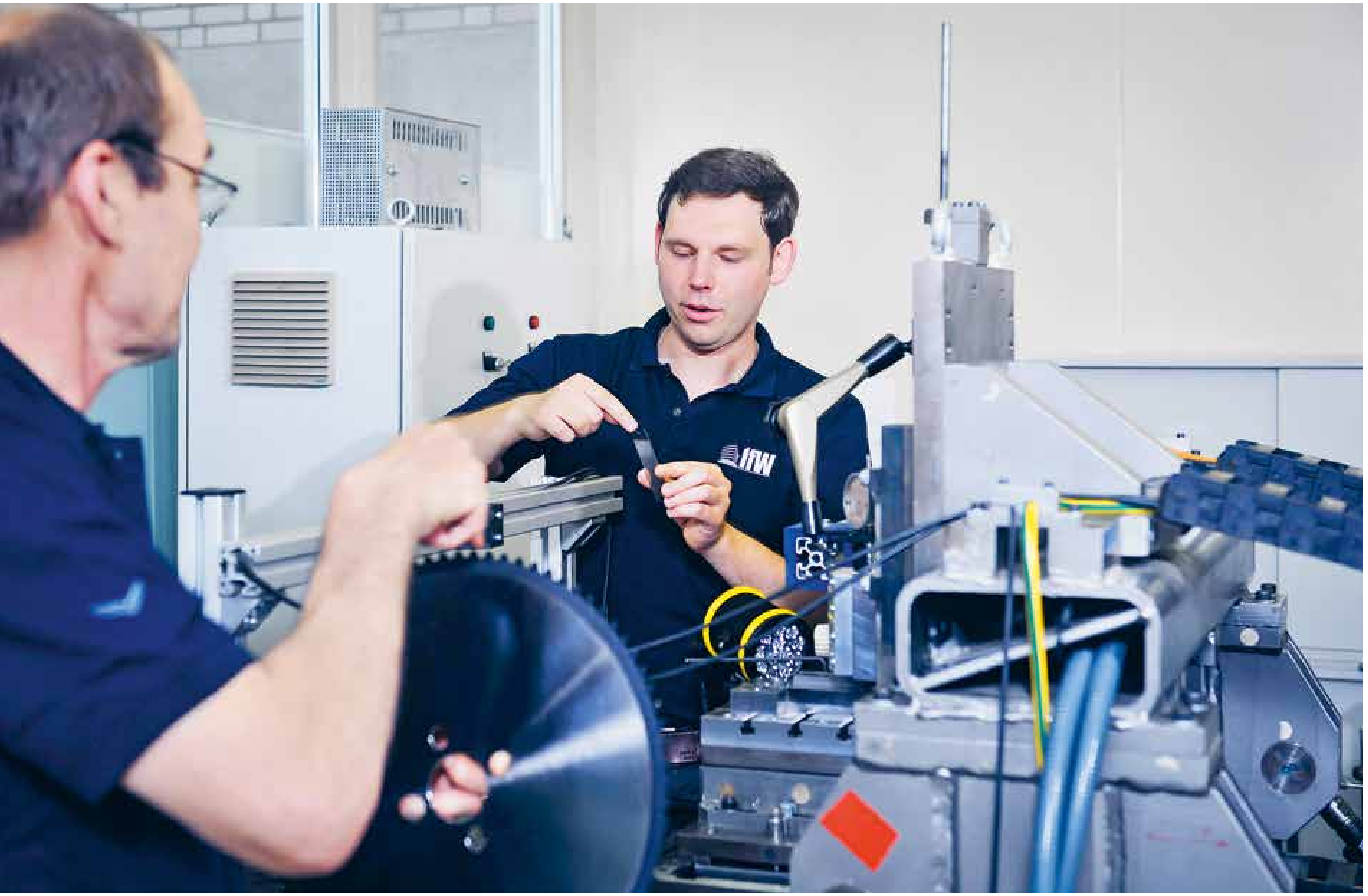
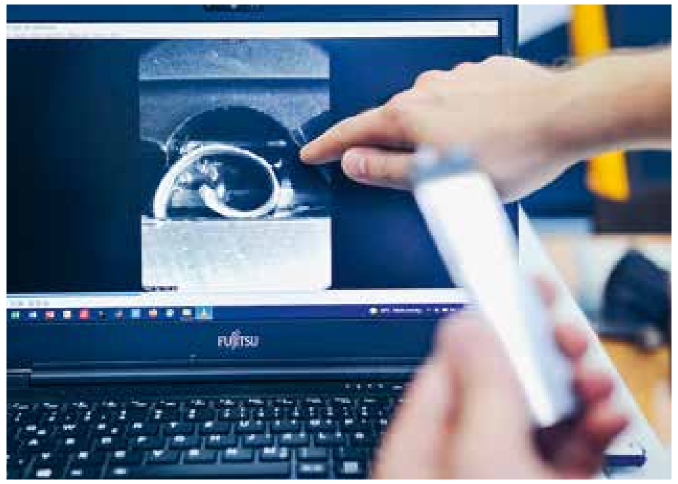


Crucial interplay: researchers at the IfW are studying the relationship between material wear and the cooling lubricant during the sawing process.



Innovative approaches: simulation researchers are adopting new approaches to make problems tractable.

Prof. Hans-Christian Möhring

"A sawing simulation such as this is completely unchartered territory. This is where modern computers come up against their performance limits."

Smart manufacturing

TEXT: Michael Vogel
PHOTOS: Max Kovalenko

Industrial production has to become more sustainable and efficient. The Institute for Machine Tools (IfW) is conducting research into how simulations and data could help with this.

Designing future industrial manufacturing processes will require computing power, performance data, and model data. Digitalization opens up the possibility for production systems to function in an automated and networked manner. "This could reduce the consumption of resources or increase the availability of machines," says Prof. Hans-Christian Möhring, director of the Institute for Machine Tools (IfW). An IfW project launched in late 2020 shows that even supposedly trivial things such as cooling lubricants pose completely new challenges.

"Production processes are not only influenced by the respective material and tool properties, but also by such things as the processes taking place in the immediate zone around where a workpiece is being machined," Möhring explains. Cooling lubricants are often used in machining processes such as drilling, sawing or milling as they decrease the friction between tool and workpiece and dissipate heat and swarf. "Until now," says Möhring, "the amount of cooling lubricant applied has mostly been calculated according to the motto 'a lot helps a lot'." Yet, cooling lubricants account for a significant proportion – between 8 and 17 percent – of total production costs according to a study carried out by the Association of German Engineers (VDI) in 2017. The lion's share of these costs is incurred when disposing of the waste products.

"In one of our current projects we are simulating a sawing process to study the interplay between material removal and the cooling lubricant ," Möhring explains. "We want to use the results to find out how we can slow tool wear whilst using as little cooling lubricant as possible." This requires a so-called multiphysics simulation, which takes account of both the mechanical and the fluid-mechanical processes involved in the sawing process as well as the heat generation. The project is part of a German Research Foundation (DFG) priority program. "A sawing simulation such as this is completely unchartered territory," says Möhring: "This is where modern computers come up against their performance limits." So, novel modeling concepts are required just to make the problem tractable. The IfW team will also have to utilize the High Performance Computing Center Stuttgart's (HLRS) computing resources.

SELF-TUNING OF DEEP DRILLING PROCESSES

Perhaps rather unexpectedly at first glance, simulations are also being used in another IfW project concerning the autonomous self-optimization of deep drilling processes. In deep drilling, the depth of the bore hole is much greater than its diameter. "The process," Möhring explains, "plays a role in cooling and lubrication channels or, for example, in bore holes in which a piston is to operate. Any cracks or nicks on the surface of such bore holes in hydraulic systems or in the high-pressure components of an engine injection system could cause the component to fail." However, defects such as these do occur when, for example, the temperature within the bore hole is too high or the feed rate too fast. Because they are drilled late in the production process, when the component already has a very high value, these bore holes need to be handled with care: damage caused by deep drilling is always costly. →

→ "Our goal," says Möhring, "is to develop a drilling system that independently optimizes the process based on the conditions within the effective zone thus maximizing the quality." But, this effective zone, the front line of the borehole as it were, is not directly accessible to sensors. "That's why we've developed a drill bit with integrated temperature and acceleration sensors. We also record the feed and torque forces acting on the drill rod." However, it is not possible to derive the appropriate rotation and feed rate for the drilling system based on this data. "To control the deep drilling process so that all parameters remain within the specified tolerances," Möhring explains, "we have to simulate the machining process and then use the simulation data to form a link between the sensor data and what is actually occurring on the workpiece." The IfW team is also developing this approach as part of a DFG priority program. ⇥

DIGITAL WOOD LABORATORY

A proving ground for students and companies

The Institute for Machine Tools (IfW) is digitizing its woodworking machinery. As Kamil Güzel, head of woodworking at the IfW, explains: "We want to demonstrate how data recorded from processes, machines and tools can be used to improve production." The laboratory equipment comprises three- and five-axis machining centers, automatic planing and molding machines, various saws, a grinder, an industrial robot and a jointer. "The typical equipment that would be used by a medium-sized furniture manufacturer," says Güzel. Some of the machines are just a few years old, whilst others are decades old, and they are all from different manufacturers. "Thus, we are demonstrating that digitalization can also be implemented in existing stock." The electrical engineering group Schneider Electric is helping with the sensor technology and data consolidation, whilst Tapio is responsible for data management and connecting to the cloud.

Some of the typical application scenarios that the project participants want to demonstrate include predictive machine maintenance, tool lifespan optimization, and the use of AI to identify improvement potential in development and production. An augmented reality application is also being developed, which will enable the projection of contextual information onto a pair of data glasses for people still familiarizing themselves with the machines.
"We already have a tablet-based prototype," says Güzel.

As of the 2022 summer semester, master's students will complete traineeships in the digital wood laboratory. Information events for small and medium-sized enterprises will also be starting before the end of the year: "The plan," says Güzel, "is to show interested parties, both online and in the lab' what a digital retrofit would enable them to do."

Kamil Güzel

"We want to demonstrate how data recorded from processes, machines and tools can be used to improve production."

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CERAMICS RATHER THAN PLASTICS

Innovative technical ceramics: 3D circuit carrier

TEXT: Michael Vogel

The housings used in modern microsystems are being made of technical ceramics.

Even the best quality electronic and micromechanical components will fail if they are not adequately protected from environmental influences. They will only work reliably – even beyond their nominal service life – if they are placed within the correct housing. Such housings are often made of plastic, because it is easy to use, cheap and lightweight. Using as few process steps as possible, manufacturers are attempting to functionalize these protective housings by making them into circuit carriers to reduce costs and weight even further. Smartphones, in which the antennae are integrated into the inside walls of their housings, are a good example of this.

But whereas integrated plastic housings are usually sufficient in consumer goods, they reach their limits in other areas. "More and more high-performance electronics are being used in vehicles," says Dr. Thomas Günther, Deputy Director of the University of Stuttgart's Institute for Microintegration (IFM)," and tiny little systems have to fit into a very small spaces in medical technology. Plastic housings are not able to adequately dissipate the waste heat generated in the process. At the same time, the 3D-shape-giving housings may reach their limits in terms of mechanical stability." The IFM is therefore collaborating with the Institute for Manufacturing Technologies of Ceramic Components and Composites (IFKB) and Hahn-Schickard (Hahn-Schickard-Gesellschaft für angewandte Forschung e.V.) to develop electronically functionalized technical ceramics as an alternative to plastic circuit carriers.

These are materials that one rarely comes into contact with in everyday life; they are often metal oxides, which can be injection molded – a favorable prerequisite for the production of highly complex three-dimensional components in large quantities. "In the context of this collaboration," Günther explains," the IFKB is developing novel aluminum oxide-based material mixtures that are suitable for such housings." These technical ceramics have favorable mechanical properties over a wide temperature range and also dissipate heat, are chemically non reactive with their environment, and can be hermetically sealed. But, the ceramics must be capable of being activated by laser and then selectively metallized in order to create conductor paths: the IFM is conducting detailed research into these process steps.

"The two Institutes are demonstrating the feasibility of this process in principle," says Günther: However, the process has to be production-ready for industrial implementation and must work reliably with much cheaper laser sources. Hahn-Schickard has been tasked with this technology transfer." So, the 3D ceramic circuit carriers are well on their way to becoming the ideal basis for modern microsystems. ⇥

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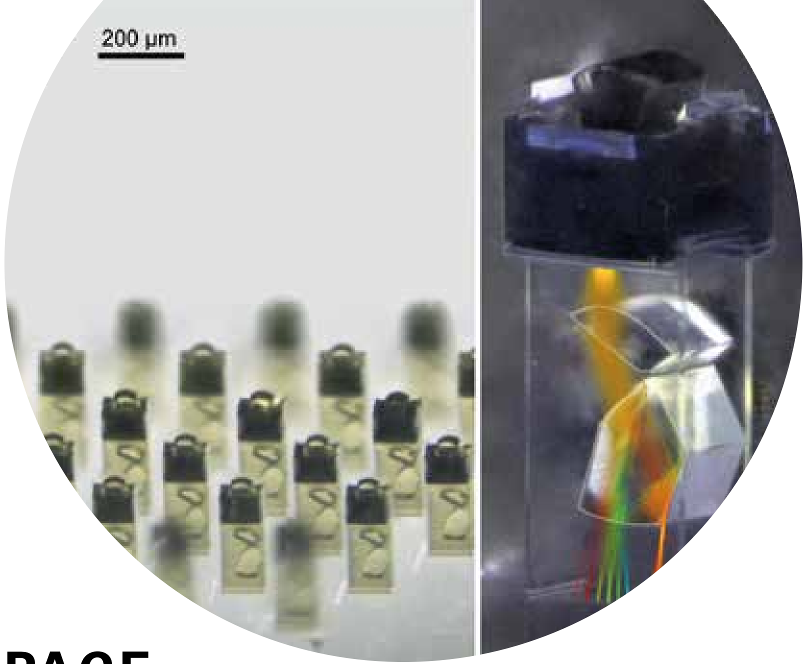
Photo: Hahn-Schickard



Complex midget: a spectrometer developed at the Institute of Applied Optics (ITO) and produced using 3D printing, has a diameter of just 0.1 by 0.1 millimeters.

NOT MUCH SPACE, BUT LOADS OF POTENTIAL

TEXT: MICHAEL VOGEL

3D printing is creating more latitude for the development of micro-optics, which are needed in such fields as medical engineering. One specific 3D printing process is particularly promising.

Optics components, like their microelectronics counterparts, are continuing to shrink. Whereas camera lenses used to be the size of a fist, a modern smartphone lens is just a few millimeters in diameter, yet the photos taken through it are still impressive. And this push for miniaturization is far from over. To exploit the full potential of future applications, particularly in the fields of medical engineering, metrology and robotics, optics will have to morph into micro-optics. For example, for a surgical team to be able decide how much of a tumor to remove during an ongoing operation they would need an endoscope equipped with some sophisticated micro-optics. In an automated agricultural setting, on the other hand, drones equipped with micro-optics could help to ensure the targeted and therefore more environmentally friendly destruction of weeds.

SUB-MICROMETER STRUCTURES POSSIBLE

For her doctoral thesis, Andrea Toulouse is looking into the amount of complexity and functionality that could be accommodated in a tiny space within a micro-optics system. The physicist is conducting her research as a member of Prof. Alois Herkommer's team, who is the head of the University of Stuttgart's Institute of Applied Optics (ITO). Toulouse is using a special 3D printing process known as two-photon laser direct writing to manufacture suitable optics: "The principle was first demonstrated in the 1990s, and scientific publications about the method are now appearing on a weekly basis." →

→ Two-photon laser direct writing involves hardening an area on a light-sensitive coating at the focal point of a laser beam, which enables the gradual creation of three-dimensional structures of virtually limitless complexity. "Because the photochemical reaction only takes place on that tiny part of the coating upon which the focal point of the laser beam is focused," Toulouse explains, "we can create extremely fine structures far smaller than one micrometer."

The development of a tiny monolithic spectrometer illustrates the potential of this technology. The ITO team co-published their project results in 2021 with another group headed up by Prof. Harald Giessen of the 4th Physics Institute. The two Institutes have already been collaborating successfully on the development of micro-optics at the Stuttgart Research Center of Photonic Engineering (SCoPE) since 2015. The projects are joint funded by the University of Stuttgart, the German Federal Ministry of Education and Research, the Baden-Württemberg Foundation, the European Research Council, the Baden-Württemberg Ministry of Science, Research and the Arts, and the Vector Foundation.

A spectrometer provides information about an object at different wavelengths; one can think of it as if the incoming light is simultaneously captured by different filters. The dimensions of the spectrometer in whose development Toulouse played a major role are just 0.1 mm x 0.1 mm x 0.3 mm: although it is such a tiny device, it comprises five optical elements, some of which are elaborately shaped, in addition to apertures and mechanical mounts. The entire thing was created using two-photon laser direct writing.

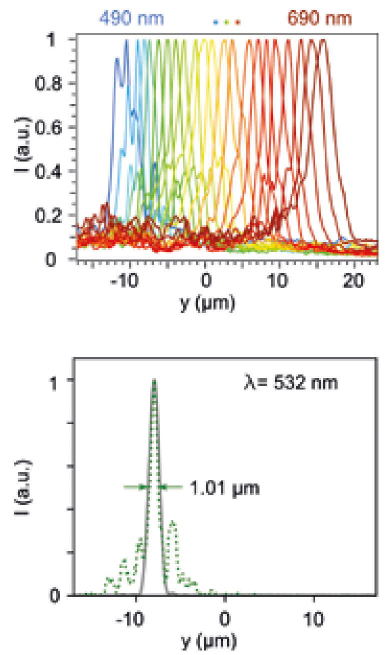
The dimensions of current spectrometers used in research that work in a comparable way are at least 100 times greater than that developed by the team in Stuttgart. Although spectrometers with around the same dimensions as the one developed in Stuttgart do exist, they work differently and the calibration process is more complex.

INCREASING INTEREST IN THE INDUSTRIAL SECTOR

Contemporary micro-optics, such as the mass produced camera lenses used in smartphones, are often made of injection molded plastics. "For large volumes," as Toulouse explains, "this method is faster and cheaper than 3D printing. But 3D printing is more cost-effective for prototypes, one-offs and small batches because the high cost of injection molding would make it unprofitable in these cases." Another benefit of two-photon laser direct writing in particular is that the geometry of the optics can be chosen much more freely and there is no need to subsequently assemble the individual components into a complete system.

"It took just under two hours to print the spectrometer," Toulouse says. "The rule of thumb for two-photon laser direct writing is that it takes 24 hours to complete an entire cycle." A cycle includes the optical and mechanical design sequence, preparing the data for printing, the actual printing process, and the subsequent metrological inspection of the optics. Whilst other 3D printing processes also require the optical surfaces to be polished, two-photon laser direct writing renders this step unnecessary.

Given its potential, it is no wonder that interest within the industrial sector is gradually increasing as well, which is why two ITO employees, Simon Thiele and Nils Fahrbach, founded the spin-off Printoptics in 2020. The start-up is already collaborating in pilot projects with its first clients. ⇥



Simultaneous detection: A spectrometer provides information about the composition of the wavelengths of an object.

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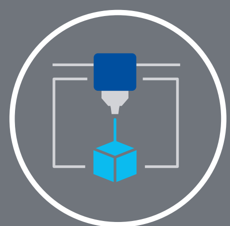
Photos and illustrations: ITO/Toulouse, A. et al. (2021). 3D-printed miniature spectrometer for the visible range with a 100×100 µm² footprint. Light: Advanced Manufacturing, 2(1), 1-11.

ADVANCED MANUFACTURING IN FIGURES

Why does the world need advanced manufacturing? This was the key question raised when we began planning the current issue of forschung leben: “what would the world be without it?” asked one of the participating professors spontaneously. Advanced manufacturing has a long tradition in fact, including at the University of Stuttgart, but the field has been fundamentally transformed over the years. Whereas the term initially referred to the transformable factory, contemporary advanced manufacturing practice combines 3D printing, digitalization, automation, chemistry, and biotechnology. If implemented in a consistent manner, this combination could potentially bring about a fundamental revolution in industrial manufacturing. It not only affects all areas of production and value creation chains, but also employment, and indeed the whole of society.

12.6 billion

USD was what the global additive manufacturing market was worth in 2020, according to figures from the online platform 3D Hubs.



30%

The German Federal Ministry of Education and Research is expecting a growth rate in the additive manufacturing sector in excess of 30 percent over the coming years. Whilst the main materials used in 3D printing are currently plastics, market growth is likely to be driven by the use of metallic materials in the future.

12 Institutes from four faculties are currently collaborating at the Stuttgart Center for Production Technology, and more are set to follow suit.

42 Institutes are united in the University of Stuttgart’s Departments of Energy-, Process-, Bio-, Construction-, Production- and Automotive Engineering. Spread over two faculties, these form one of Germany’s largest mechanical engineering centers.

467

The University of Stuttgart’s Collaborative Research Center SFB 467 (Transformable Business Structures for Multiple-Variant Series Production) has been doing groundbreaking basic research in the field of advanced manufacturing since 1997.

2008 was the year in which the “Graduate School of Excellence advanced Manufacturing Engineering” (GSaME), one of the University of Stuttgart’s first two excellence projects, was founded. The GSaME’s main purpose is the sustainable further development of the scientific basis for Advanced Industrial Engineering and to provide excellent interdisciplinary training for managers, engineers and scientists.

Novel navigation: Prof. Nejila Parspour and doctoral student Javier Stillig of the “Scooty Inductive” development team

WIRELESS COMMODITY FLOW

Standardized size: the small load carriers that “Scooty” transports are common in production logistics.

TEXT: Daniel Völpel
PHOTOS: Uli Regenscheit

Industrial manufacturing has to become more flexible because the market is demanding an ever increasing number of bespoke products, and fixed production systems are reaching their limits. One potential solution to this problem is currently whizzing around the University of Stuttgart’s ARENA2036 research campus in the shape of the “Scooty”.

A driverless transport vehicle developed by an interdisciplinary team in the course of the University of Stuttgart’s “Scooty Inductive” project measures just 60 by 40 centimeters but solves some major challenges and features several innovations compared to other models. Not only can the vehicle maneuver on flat surfaces, it can also navigate any angle and turn on the spot. It recharges itself by means of inductive energy transfer via a special raised floor, which saves battery space and eliminates downtime for charging. When future production facilities are configured in a modular fashion and frequently reconfigured, the transporter will be able to respond easily by seeking out new routes.

The idea was hatched when experts from two different disciplines began talking at the ARENA2036 research campus: one team headed up by Director Prof. Nejila Parspour of the Institute of Electrical Energy Conversion (IEW) is researching the contactless energy transmission system among other things. Meanwhile, other researchers at the Institute of Mechanical Handling and Logistics (IFT) are studying changeable production logistics. IFT Director Prof. Robert Schulz explains: “We are currently seeing more driverless transport vehicles in the field of intralogistics because manufacturers are trying to make their processes more flexible. This type of transport vehicle is ideal for manufacturers who wish to produce a wide variety of products in a single manufacturing facility, because they need parts to be supplied in a flexible manner rather than via rigid conveyor systems.” Because these vehicles need to be controlled, navigated and tracked, he goes on to say, they need a power supply. “Hence our collaboration with the IEW because inductive charging makes sense in this case."

ELECTRIC SCOOTER WHEELS

Within a year and with almost 50,000 euro of funding from the University of Stuttgart, the project partners had put the first “Scooty” on its wheels, which, as it happens, gave the system its name as powered wheels from electric scooters proved to be the ideal rollers. For the purposes of the model, the team installed them in separate drive-steering modules each of which can be rotated 320 degrees.

According to Nejila Parspour, she realized some 15 years ago that small, agile robots capable of moving in any direction would one day be needed in production facilities. “But how can the power supply be guaranteed if the magnetic field is needed everywhere?” she asks rhetorically: “We’re now closing in on our goal of supplying these vehicles with power without having to power the entire floor, whereby the modularity we’ve managed to achieve is the special thing.” →

Left: Shared challenges: Prof. Robert Schulz, Head of the Institute of Mechanical Handling and Logistics (IFT), with Carolin Brenner and André Colomb

Right: Ongoing optimization: an insight into the inner workings of "Scooty"

→ This, as doctoral student Javier Stillig explains, is because the raised floor is made up of 60 by 60 centimeter tiles, each of which contains five coils each capable of delivering 500 watts of power. Following some initial laboratory tests, the team produced 30 coils and developed the magnetically soft materials they require. Next, the magnetic cores were cast, because – as Stillig goes on to say – a magnetic conductor needs to be installed on the back of the coils to close the field. The system is currently undergoing field trials. Halls in Industry 4.0 factories could also be supplied with water, compressed air, operating materials or electricity for machines and tools via the raised floor, which also contains navigation and tracking elements for vehicles. "The raised floor technology gives me an overview of where my vehicles are and what they are doing," says IFT manager Robert Schulz, "and, for example, I could design safety concepts for obscured sections within the factory hall."

As André Colomb, a research associate at the IFT, explains, the group deliberately chose a small-load-sized transport vehicle. With its small dimensions, "Scooty" can carry the type of standardized small load carriers widely used in production logistics piggyback. "There aren't a lot of omni-directional vehicles in this size class," he explains: "The challenge was to implement surface mobility in a load carrier of this size." In addition to the motor, the loading coils, control system and the sensors all had to be accommodated. The system can now be scaled up by simply mounting any number of wheels on a chassis of any size.

Carolin Brenner

"Using the coil signals to navigate was also a major challenge."

A COMPLETELY NOVEL CONTROL SYSTEM

"Using the coil signals to navigate was also a major challenge," as Carolin Brenner, a research assistant at the IFT, explains. "The floor maps out the route by turning on individual panels and guiding the vehicle via the inductive signals just as a guidance control system would otherwise do. Vehicle mounted sensors measure the inductive signals in the floor and 'Scooty' follows them. This is a novel approach to designing vehicle guidance systems in intralogistics."

Depending on the size of the vehicle, says Javier Stillig, several modules can be used simultaneously to transmit different levels of power. "Connecting several modules creates a parallel operation, which enables us to provide about six or eight kilowatts of power within a square meter." The "Scooty" prototype is also fitted with an 18-volt battery. →

André Colomb

"There aren't a lot of omni-directional vehicles in this size class."

→ "This can be used to traverse difficult areas where one might not want to modify the floor," Parspour explains. But, he goes on, you can also drive without a battery if the power supply is ubiquitous.

She is currently carrying out further basic research to make this even easier and cheaper in the future: "We are collaborating with Stanford University to gain access to the very high frequency area – higher than what has been used before," Parspour explains: "The benefit of that would be that instead of having to construct individual coils, we could 3D print the windings and therefore manufacture much smaller power electronic components." Parspour also has another vision for "Scooty Inductive." "As a scientist who deals with efficient energy conversion day in day out, I hate to see energy being converted to heat because it often goes unused, which is why we are always trying to increase efficiency. In a fleet of intercommunicating smart vehicles, one of them that happens to be braking could surrender some of its energy to another that is in the process of accelerating. After all, inductive charging systems enable a two-way energy flow." ⇥

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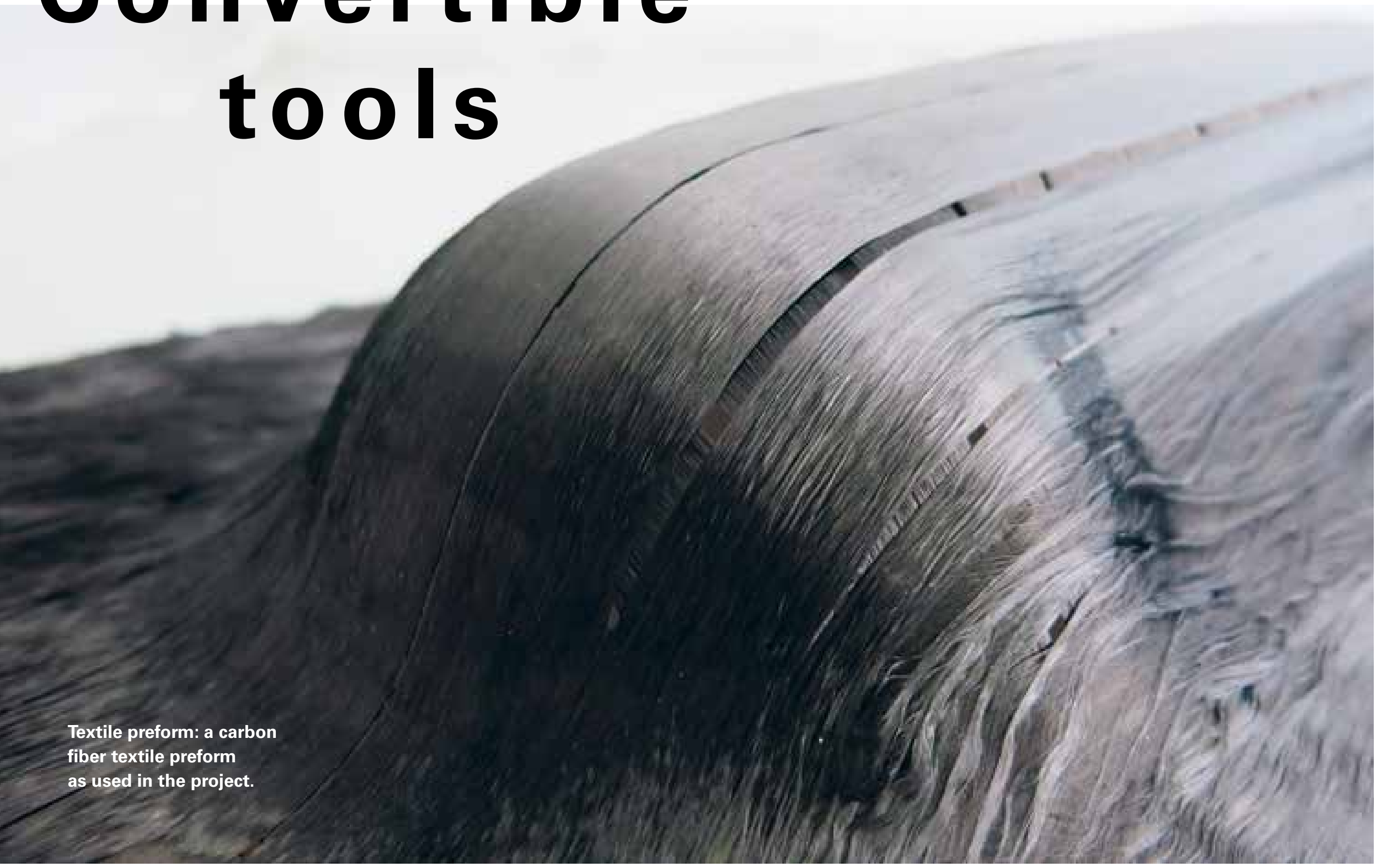
Convertible tools



Textile preform: a carbon fiber textile preform as used in the project.

TEXT: Daniel Völpel

Rapidly adaptable and capable of being monitored constantly by sensors: that is how a new production process being developed in an ARENA2036 research campus project could conserve resources and reduce manufacturing costs.

Metallic manufacturing tools are expensive to produce and can often no longer be used if the workpiece is modified just slightly. Tools that could be modified as required would be considerably more favorable for production, especially of small batch runs. Researchers at the University of Stuttgart's Institute of Aircraft Design (IFB) have collaborated with industrial partners and other universities to develop just such an approach that makes use of form-adaptive tool systems and the analysis of textile sensor technology.

As doctoral student Michael Liebl explains, one of the first components to be created using the novel manufacturing process will be a battery casing. Liebl is the IFB project manager for the "Digital Reconfigurable Manufacturing of Fiber Composite Components in a Resilient Production Environment" (DIREKT) project, which the German Federal Ministry of Education and Research (BMBF) is funding with two million euro. As Liebl reports, a little over a year and a half after the start of the University of Stuttgart's ARENA2036 research campus focus project, the first series of empirical tests are about to begin.

ENTIRE GEOMETRY CHANGEABLE

To be able to produce carbon fiber-reinforced composite (CFRP) components in a flexible manner, DIREKT is focusing on several key issues: industry partner Cikoni GmbH, for →

Modifiable geometry: the team is using the Dynapixel technology developed by their partner Cikoni GmbH for this purpose.

→ example, is contributing its Dynapixel technology, which avoids having to use a rigid mold into which the fibers are placed to give them their form while they cure. Instead, the mold comprises numerous rounded and height-adjustable metal pins, which enable the entire geometry of the tool to be modified.

The system is supplemented by a textile strain sensor, which the aircraft manufacturers developed in collaboration with the Innovative Print Technology Applications research group at the Stuttgart Media University. Because the sensor can only be used once at present, it must be easy and inexpensive to produce. "To achieve this," Liebl explains, "a conductive silver paste is printed onto a stretchable film in a screen printing process. The resistivity changes in line with the spacing of the silver particles from which one can determine the elongation."

It is possible to place the sensor on the workpiece to monitor whether limit values have been exceeded during the forming process. Whilst it is not possible to change the tool geometry during a forming process, which only lasts 30 to 50 seconds, "the mold can be adjusted for the next workpiece if problems are encountered," says Liebl. It is also possible to intervene during the forming process, for example, via the temperature or the clamps that hold the textile in place around the mold to which end the team developed a segmented clamping system with 28 individual dies, which replace the rigid frame that is usually used. The long-term objective, as Florian Helber, research group leader for fiber composite technology at the IFB explains, is to also use sensors from the manufacturing process throughout the component life cycle to measure such things as vibrations or damages although, as he points out, this is not yet a project focus.

DIREKT:

Digital Reconfigurable Manufacturing of Fiber Composite Components in a Resilient Production Environment

DIREKT is halfway towards achieving its objectives, says Liebl: "The system has been prepared, programmed and assembled on site. We will fit the sensor technology and see where it can best be used and how it interacts with the material." This is because the carbon fiber "wallpaper" supplied by project partners M&A Dieterle GmbH and Kejora GmbH has hardly ever been used in forming technology before.

HALVING THE PRODUCTION COSTS

Another project partner, sensor and automation specialist Balluff GmbH, is responsible for the control electronics and the data analysis. The ultimate objective of the DIREKT project is to demonstrate how the adaptable tool, laying robots for the textiles and sensor technology can be used to manufacture real CFRP components from the digital data of a specific component, which could potentially reduce production costs by half, especially for small batch runs.

The production data from the battery casing has already been forwarded from an ARENA2036 sister project. The DIREKT team is also working closely with the partner project "Global Innovation Linkage" at the Swinburne University of Technology in Melbourne, which is involved in the automated large volume production of fiber composites and is in the process of constructing an innovative research center for this purpose. The Stuttgart-based researchers want to test their sensor technology in this industry-oriented facility among other things. ⇥

The textile is given its 3D format on the drapery test stand.

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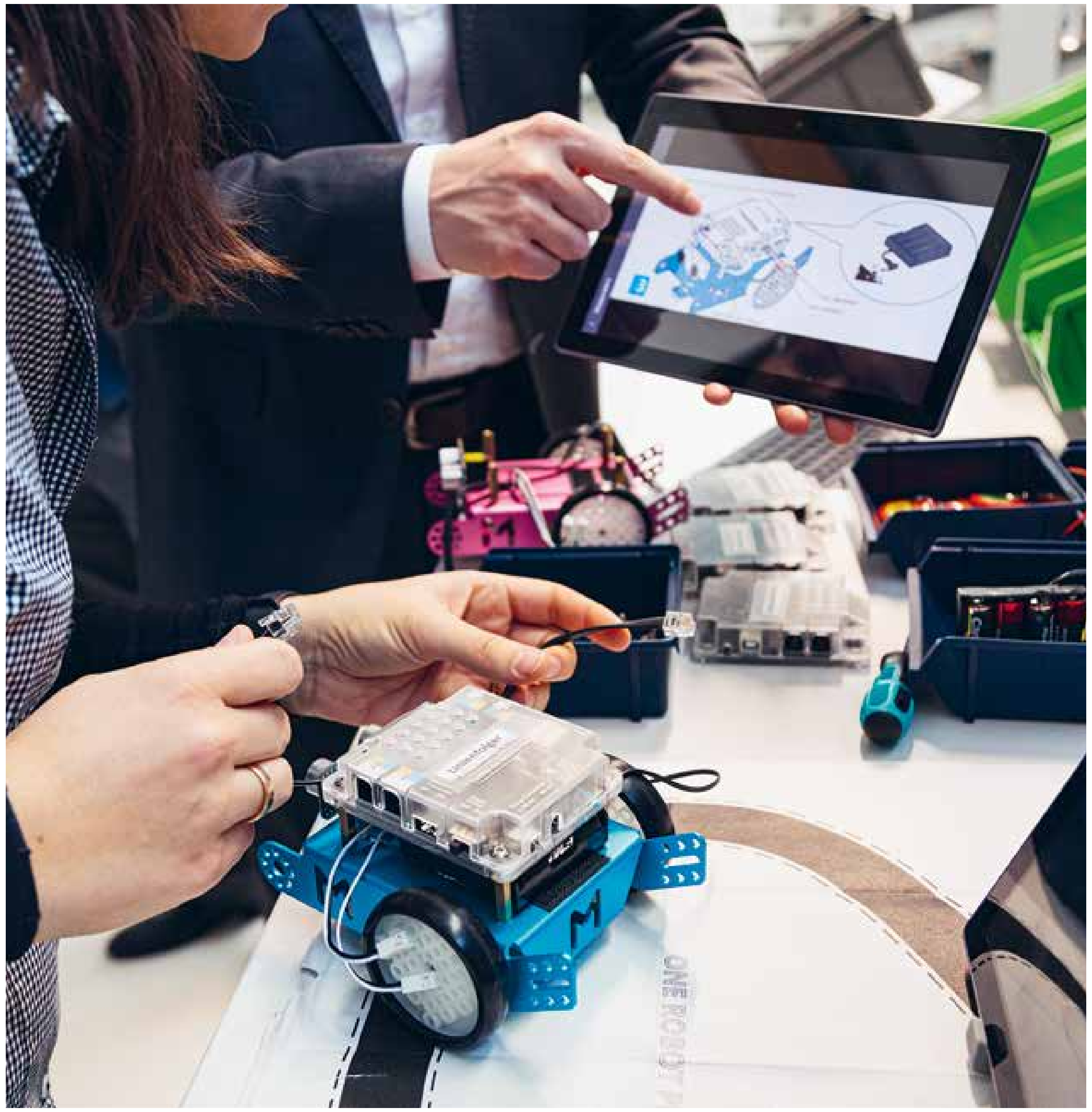
Photos: University of Stuttgart / IFB

Personalized and inexpensive



User-oriented approach: advanced training at the Mass Personalization High Performance Center

Photos: p. 52 Fraunhofer/IPA, p. 53 University of Stuttgart

Multifaceted expertise: according to Prof. Peter Middendorf, the University of Stuttgart's spokesman for the Mass Personalization High Performance Center, it gives partners unique access opportunities.

TEXT: Bettina Künzler

The objective is to enable companies to be able to manufacture bespoke products in a cost-effective manner. The Mass Personalization High Performance Center is collaborating with the industrial sector to develop processes and business models.

Individualization is a mega trend that is having a decisive effect on contemporary society, which is evident, for example, in the increased demand for bespoke products and services. How can companies find out whether personalized production would be worth their while? How can they adapt products or services to individual needs and still manufacture things in a cost-effective manner?

The Mass Personalization High Performance Center is a joint initiative of the University of Stuttgart and the Stuttgart-based Fraunhofer Institutes. Researchers there are developing interdisciplinary and cross-sector methods, procedures, processes, production systems and business models for the creation of bespoke products. "Mass personalization" involves a new, holistic product manufacturing approach, as Prof. Peter Middendorf, spokesman for University of Stuttgart's High Performance Center explains. The users are the main focus and the bespoke products and services do not cost much more than mass-produced goods.

"Our current production technology is geared up for efficiency and is based mainly on achieving a high degree of product uniformity, which is the credo of mass production. And this is important because it gives us cheap products. So, among other things, manufacturing bespoke goods for the masses will require new manufacturing technologies."

BESPOKE MEDICAL ENGINEERING PRODUCTS

To bring basic fabrication research and biomaterial technologies for bespoke biomedical systems together, the University of Stuttgart founded a Stuttgart Partnership Initiative, in which nine University Institutes are currently participating. Bespoke medical "→

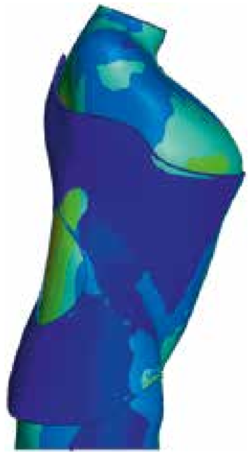
Prof. Peter Middendorf

"Among other things, manufacturing bespoke goods for the masses will require new manufacturing technologies."

→ technology is urgently needed from a patients' perspective, because humans are not standardized off-the-shelf products," says Prof. Günter Tovar, the spokesman of the initiative.

Bespoke medical engineering promises a long-term, sustainable use in future healthcare and therapy. Several University of Stuttgart Institutes are carrying out collaborative research with the Fraunhofer Society, into such things as bespoke corsets and cartilage implants. Dr. Okan Avci, Deputy Head of Department for Biomechatronic Systems at the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA), and his team are developing digital networks, business models and data systems in addition to setting up digitized medical engineering processes without which, a cost-efficient production of bespoke products would not be possible.

"In addition to orthopedic technicians," as Avci explains, "there isa plethora of specialists employed in the field of medical engineering, such as mensuration technicians, IT experts and simulation engineers, all of whom are needed, forexample, to analyze the effectiveness and wearing comfort of a bespoke scoliosis corset, to test its stability and to produce it at a cost-effective price." The work involved is extremely time-consuming and expensive and yet, as Avci goes on to say, these corsets, which are required exclusively by children and adolescents, are often clunky, stiff, oversized and uncomfortable. →



Bespoke medical technology for use in such things as scoliosis corsets.

Automated production: a printed knee cartilage implant

Promising prospects: an insight into the work carried out at the Hight Performance Center

Photos: p. 54 Fraunhofer/IPA (2), University of Stuttgart, p. 55 University of Stuttgart

→ That is why Avci and his colleagues are developing a virtual testing system for people who need a scoliosis corset to correct their spinal curvature, which will enable patients to try on a virtual version of the corset first. This involves simulating such things as height and movement behavior data to illustrate how the corset will behave when the respective patient moves. "We enter the data from the corset and the human into our virtual testing system, which computes and optimizes the data and shows us what the final corset should be like for each patient to optimize freedom of movement, eliminate pressure points and still be sufficiently stable."

BONE-CARTILAGE IMPLANTS MADE OF BIOMATERIALS

The additive manufacturing of personalized products relies on data from detailed analyses. Another project currently being run at the Mass Personalization High Performance Center is focused on the additive manufacturing of personalized cartilage implants. Osteoarthritis of the knee can be caused by misalignment, obesity or competitive sports and patients suffer from pain and restricted mobility. The project is aimed at the development of an end-to-end automated process chain from the CT scan to the bespoke implant, facilitated by a comprehensive process optimization.

The project is being supervised by Frederik Wulle of the University of Stuttgart's Institute for Control Engineering of Machine Tools and Manufacturing Units (ISW) and his colleagues, who are investigating ways of manufacturing bespoke biological bone-cartilage implants from biomaterials in an automated manner. Wulle is responsible for the additive manufacturing of the implants using 3D printing technology. "We generate the geometry to be printed on the basis of the biomechanical data and the reconstruction geometry." The necessary data is supplied by colleagues at the IPA, where researchers use analysis data of the musculoskeletal system to derive information about such parameters as the requisite size and stiffness of the bespoke cartilage implants so that they optimally match the patient's individual biology and biomechanics and enable a successful course of therapy.

Wulle and his colleagues use this data to reconstruct the nominal geometry of the defective body part to be replaced using computer-aided design technology. Additive manufacturing processes are used to construct objects with a correspondingly complex geometry from different materials. To manufacture the cartilage implants the team relies on innovative multi-axis 3D printing and machining technology, the advantage of which is greater process freedom compared to the conventional three-axis process. It can, for example, minimize the step effect that happens when a component contour is not parallel or orthogonal to the build direction, which subdivides the slope into discrete layers.

The bone-cartilage implants used in the project are made of biomaterials. The ultimate goal of the interdisciplinary field of bioprinting is to produce biomimetic tissue structures as replacements for the patients' diseased tissue, whereby they orient themselves on the biological tissue and attempt to use digital printing processes to reproduce it. The biomaterials in question are developed, produced and tested at the Institute of Interfacial Process Engineering and Plasma Technology (IGVP) and the Fraunhofer Institute for Interfacial Engineering and Biotechnology (IGB) in Stuttgart. Commenting on the interdisciplinary collaboration, Wulle explains that "we had developed the multi-axis 3D printing technology and were searching for an application when our materials development colleagues recognized its potential for their own application."

WOULD IT BE WORTH OUR WHILE?

Ever more companies are responding to the bespoke manufacturing trend, which is why The High Performance Center is offering targeted training programs for them. "Entering into a collaboration with us gives a company access to multifaceted expertise that is otherwise hardly accessible," says the spokesman for the High Performance Center, →

Frederik Wulle

"We generate the geometry to be printed on the basis of the biomechanical data and the reconstruction geometry."

Products in demand: participants at a training event indicate how interested they would be in personalized products.

Open house: High Performance Center employees inform the public about their ongoing projects.

→ Peter Middendorf: "Potential collaboration partners can use it to approach future technologies."

Lesley-Ann Mathis and her colleagues at the University of Stuttgart's Institute of Human Factors and Technology Management (IAT) have developed a method with which companies can systematically analyze their product portfolio for personalization potential to decide whether bespoke product development would be worthwhile for them. She and her team teach their method to companies in the context of continuing education seminars presented at the High Performance Center. They then offer companies a potential analysis for their specific product sets or servicesin follow-up projects.

The method they have developed is based on the so-called "product journey" and "user journey". As Mathis explains: "We take a user-centric approach in the High Performance Center: our approach starts directly with the user." To illustrate her process she uses the example of an e-scooter that can be rented via an app for a certain time and distance. During the so-called product journey, she and the seminar participants analyze the group at which the product will be targeted throughout its entire life cycle and which user groups would come into contact with the product. In the case of the e-scooter, these might include university students who would use it to travel to their next lecture, or employees who would use it to travel from the train station to the office. But the wider range of user groups includes the people who pre-assemble them, pick them up and transport them to collection points, or ultimately recycle them. This creates so-called protopersonas, such as Colin Commuter or Sandra Student, within the product journey, whose surnames obviously represent their primary characteristics.

THE ENTIRE USER JOURNEY AT A GLANCE

To map out the user journey, one of the primary target groups for the product is selected after which the seminar participants accompany, for example, Sandra Student during her entire contact with the e-scooter from when she first books it via the app to when she parks it up and leaves it. "We analyze where the user comes into direct contact with the product and assess how the user experience could be improved and where opportunities for personalization might exist," Mathis explains. All ideas are first analyzed in terms of their benefit to the user before being subjected to a cost-benefit analysis. Remaining with the example of the e-scooter, it might be possible to develop a personalized voice response system that would render the use of the smartphone app obsolete, or provide personalized pricing models for regular users and frequently used routes. →

Lesley-Ann Mathis

"We use a specific tool to identify relatively quickly and at an early product development stage whether a product is suitable for personalization and whether it would be worthwhile."

→ The holistic approach would benefit companies in various ways says Mathis: "We use a specific tool to identify relatively quickly and at an early product development stage whether a product is suitable for personalization and whether it would be worthwhile." After all, bespoke products will only be successful if they really do benefit the customer. ⇥

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Photos: Fraunhofer/IPA (3)

GREEN 3D PRINTING

TEXT: Jutta Witte

Recyclable base materials, ecologically degradable auxiliaries: scientists from the University of Stuttgart's Institute of Polymer Technology (IKT) are working on sustainable additive manufacturing processes.

A number of different production processes are covered by the term "additive manufacturing" but they all have one thing in common: unlike "subtractive manufacturing" or machining, in which a workpiece is created by removing material until the desired shape is achieved, a computer program uses a 3D model to build up plastics, metals, ceramics or synthetic resins layer by layer to form a three-dimensional workpiece. As Dr. Alexander Geyer, head of processing technology at the Institute of Polymer Technology (IKT) explains: "to the greatest extent possible, we only use as much material as we really need in 3D printing and we deposit it in exactly the right place."

LESS WAREHOUSING AND LOGISTICS

There are many benefits to additive manufacturing: most post-processing steps are eliminated; less scrap waste is created and material consumption is reduced, and it is possible to create almost any design and complex geometry. 3D printing is used to produce scale models, tools or even spares on demand, all of which are fabricated directly on site, which means that warehousing space and logistics operations can be reduced. The processes involved are still slow and not suitable for mass production, but they do open up new possibilities in industries such as medical engineering in which bespoke patient products are required, or the aerospace sector, which needs lightweight polymer-based components. →

Printed maritime products: model ships from the IKT laboratory

→ The 3D printers in the IKT lab' operate almost silently. Products from the experiments being conducted there, which include everything from trainer insoles to car brake calipers to a model ship, line the shelves. What may appear frivolous at first glance is actually helping basic research. Geyer and his team are trying to find innovative technologies to make 3D printing more sustainable whereby they are focusing on two main processes among others, which are selective laser sintering (SLS) and fused deposition modeling (FDM).

The SLS process uses a plastic powder that is finer than sand and the powder bed is melted in a construction space that is heated to high temperatures at the points specified by the 3D computer model before being lowered so that the next layer (which is just 100 micrometers thick) can be applied. The surrounding powder supports the structure and the end product can be easily extracted from it.

The problem is that around 70% of the most commonly used plastic powder is damaged by the high temperatures after which it is mixed with new powder so that it can be reused. As Dr. Sandra Weinmann, a research assistant at the IKT explains: "This results in material quality fluctuations. Regenerating the powder during the manufacturing process is more sustainable." The chemist wants to recycle the used powder by combining the powder particles with a modifier, which is designed to ensure that the material damage is repaired directly. Initial trials have been promising. One of the current tasks is to find the optimum recipe and to adapt the equipment accordingly.

Weinmann's Institute colleague, Silvia Lajewski, is working on optimizing the FDM process, which involves melting a strand of plastic in a heated nozzle before applying it to a construction platform at predefined points. The problematic parts include those structures that are supported by a second material during the manufacturing process to achieve complex geometries with such things as pronounced overhangs: these are usually dissolved in a water bath to remove them after solidification, but this pollutes wastewater with harmful microplastics. "Conventional wastewater treatment plants are unable to filter it out," says Lajewski. That is why she wants to develop a water-soluble support material that can also be biodegraded through bacterial metabolism. She is currently using a twin-component material made of polymer and a highly refined salt, the basic concept being that the salt from the finished structures dissolves in the water, which makes them so porous that they can be removed without leaving any residue. Lajewski is also working step-by-step towards finding the ideal combination between the components and to develop a usable formula.

Both projects are already attracting a great deal of interest within the industrial sector. Despite some initial successes, the researchers still have a lot of detailed work to do. For Geyer, her research is a good example of the "adjusting screws we can turn to answer key future questions in 3D printing, such as recycling and protecting resources and the environment." ⇥

Biodegradable: a support structure made of salt and polymer

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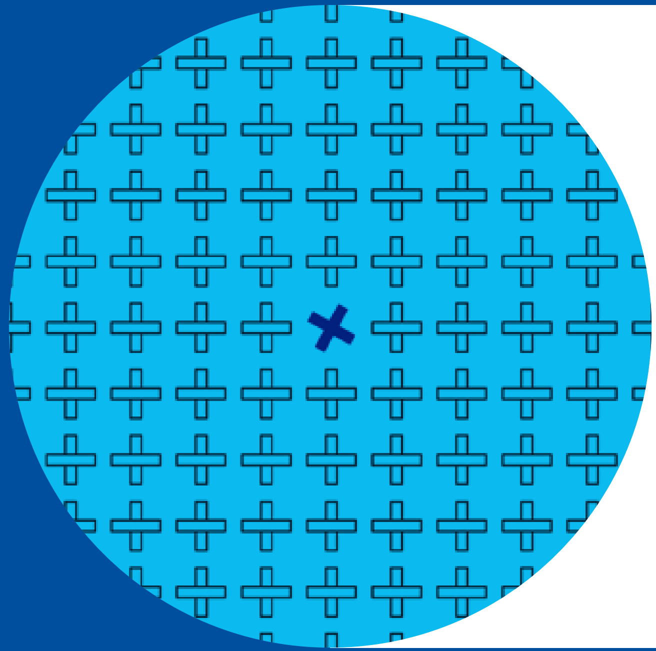
NOTE PAD



DETECTIVE WORK IN LARGE DATA STREAMS

How can the data from complex production plants be recorded, stored, processed, and analyzed throughout the entire value creation chain? This was the subject of the EMuDig 4.0 project (boosting efficiency in massive forming through the development and integration of digital technologies in the engineering process along the entire value creation chain). The consortium included the University of Stuttgart's Institute of Industrial Automation and Software Engineering (IAS, Prof. Michael Weyrich) and Institute for Metal Forming Technology (IFU, Prof. Mathias Liewald), the South Westphalia University of Applied Sciences, the industry partners Otto Fuchs KG, Hirschvogel Automotive Group, SMS group GmbH and the TU Dresden's Center for Information Services and High Performance Computing.

"The results are applicable to the entire data processing chain from acquisition to analysis within the cloud, as well as feeding the findings back into the process chain," says Benjamin Lindemann, project manager for the IAS. "We implemented a software stack which records, transforms, and compresses the relevant process and component data." Metadata was then applied to the basic data for further processing, whereby OLAP (Online Analytical Processing) technology in particular was used to rapidly process large data volumes. Recurrent (feedback) neural networks (LSTM networks/autoencoders) were used to analyze the integrated and saved data. It proved possible to use their ability to account for temporal dependencies in datasets to develop a cascaded control system for the modification of adaptive manipulated variables as well as to develop an algorithm for detecting anomalies in metal forming machine tools.

The expertise gained in the fields of data integration, modeling, and machine learning-based (e.g., neural networks) learning are now being applied and further developed in new projects at the IAS.

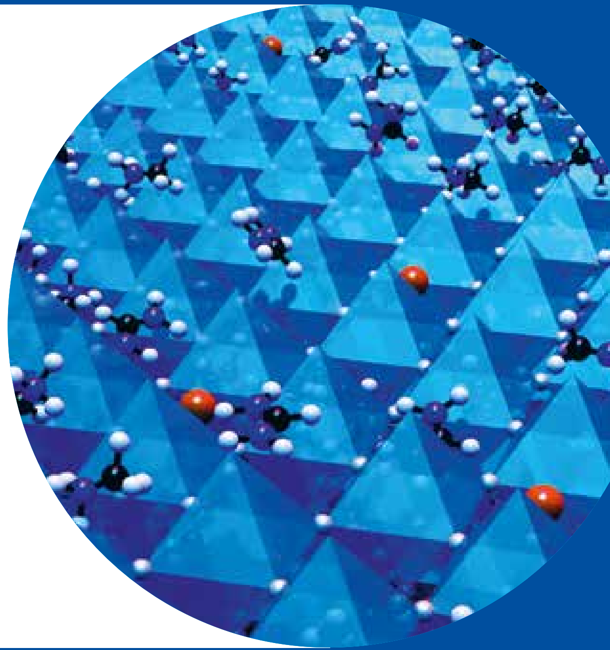
A SPLINT THAT FUNCTIONS LIKE A VINE

The air potato (Dioscorea bulbifera) climbs trees by applying its own compressive force to the trunk of the host plant. Mobile, self-adapting material systems work on a similar principle and undergo complex shape changes under the influence of moisture, contracting and expanding in a pre-programmed manner. For the first time, a new process has now made it possible to use a commercially available 3D printer to produce such material systems. It was created in a collaboration between Tiffany Cheng and Prof. Dr. Achim Menges of the University of Stuttgart's Institute for Computational Design (ICD) and the Integrative Computational Design and Construction for Architecture Cluster of Excellence (IntCDC) and Prof. Dr. Thomas Speck of the University of Freiburg's Plant Biomechanics Group and the Living, Adaptive and Energy-autonomous Materials Systems Cluster of Excellence (livMatS).

The team has produced a forearm splint as an initial prototype that automatically adapts to the wearer and which can be further developed for use in medical applications.

PEROVSKITE: MORE THAN JUST SOLAR CELLS

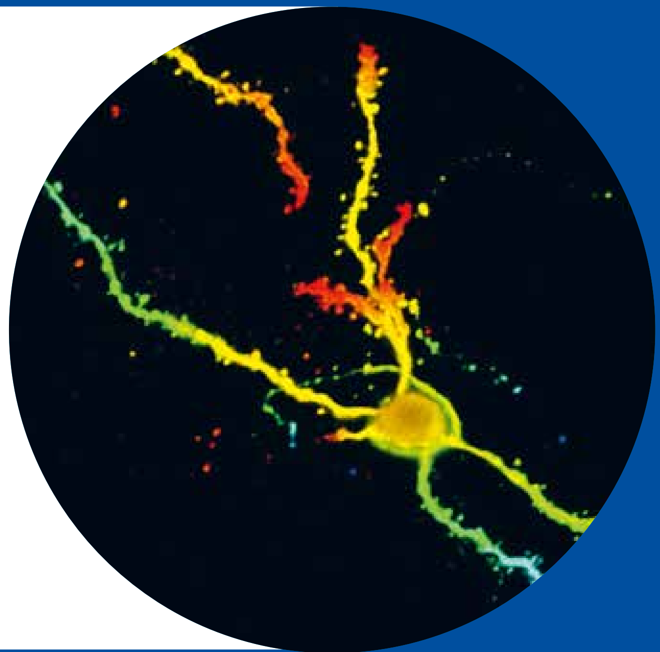
Great hopes are being placed in perovskite materials for a new generation of high-efficiency, low-cost solar cells. A group led by Prof. Michael Saliba at the University of Stuttgart's Institute for Photovoltaics (IPV) has recently demonstrated that the concept of the versatility of perovskites can be extended much further into the field of two-dimensional materials. As such, not only are perovskites suitable for use in solar cells, but they can also be conceived of as extremely thin layers, similar to two-dimensional graphene, for which the Nobel Prize was awarded in 2010. This change in perspective opens up new horizons for perovskites in fields such as spintronics and quantum computing. These research findings will then also be able to help solar cells to reach new heights.



TO FEAR OR NOT TO FEAR?

Which cerebral neurons are involved in the emergence of fear and how do they reset the switch when the danger is over? To find out, a team led by neurobiologists Prof. Ingrid Ehrlich and Dr. Ayla Aksoy-Aksel at the University of Stuttgart and researchers from Austria, Switzerland, and the United States of America, have been studying so-called intercalated cells, which surround the amygdala in clusters resembling a net. The project partners succeeded in demonstrating that a specific cluster of intercalated cells becomes active whenever mice associate a specific sound with an aversive stimulus and display a fear response to it. Another cluster becomes active when the mice learn to stop being afraid.

Photos: University of Stuttgart/IBBS/ILEK/ICD, Tiffany Cheng, Ingrid Ehrlich, Sven M. Hein



ULTRALIGHT AND SAFE

Because they require much less material, lightweight designs enable the conservation of raw materials, but they also have to be able to withstand any stress loads to which they are subjected at the same time. As these are not known in advance, engineers work with extremely conservative estimates but that means that such structures are still very over dimensioned.

Researchers at the University of Stuttgart's Collaborative Research Center 1244 have now developed active, adaptive structural elements that can be used to manipulate a structure's load transfer characteristics. This innovation is enabling the construction of so-called ultra-lightweight structures, which save even more material compared to traditional lightweight construction without reducing the structural safety. To achieve this, actuators – i.e., active elements – are integrated into the passive support structure either in parallel or in series.

Patents have been applied for the structural elements and the researchers are now looking for partners in the industrial sector for the market launch.

RETHINKING CHEMISTRY

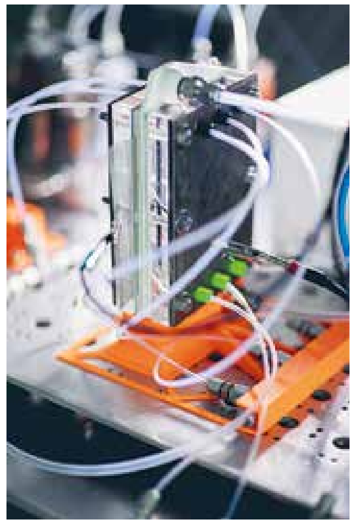
TEXT: JENS EBER
PHOTOS: ULI REGENSCHEIT

The objective of the CHEM | ampere research initiative is to provide nothing less than the scientific basis for a complete transformation of the resource-hungry chemicals sector.

"We need to rethink chemistry," according to Prof. Elias Klemm. At the core of this brief sentence, which Klemm says in an almost casual manner, lies an idea that could totally revolutionize the chemical sector. "We're turning the family tree of chemistry on its head," adds the head of at the University of Stuttgart's Institute of Chemical Technology. The idea is to transform an industry that has until now mostly drawn its energy and material resources from fossil fuels into a sustainable industry that will generate energy and raw materials from green power and air.

The idea may seem fantastic, but Klemm has both feet firmly planted on the ground of science. CHEM | ampere, of which he is the spokesman, is a research initiative based in Stuttgart whose core focus is on a near future in which humanity will no longer emit carbon dioxide from fossil sources.

The German government recently decided that Germany would become climate-neutral by 2045 rather than 2050 as previously planned. Greenhouse gases are to be reduced by 65 percent by 2030 compared with 1990 levels. The chemical industry currently produces around ten percent of CO_2 emissions in Germany, around half of which comes from the energy required for various production processes as well as from direct CO_2 emissions from the factories. The other half comes from petroleum and other raw materials, which are processed into various products that eventually get released into the atmosphere in the form of CO_2.



Research for sustainability: renewable energy is used to convert carbon dioxide into formic acid in the laboratory-based reactor.

INTERDISCIPLINARY RESEARCH TEAM

Whilst it is relatively easy to imagine replacing process energy generated from oil, coal or gas with electricity from renewable sources, exploiting completely different raw materials to continue to produce plastics, paints and thousands of other products presents an enormous challenge. "This gives the chemical sector a lot of space for development," says Klemm, describing the appeal of the task: "we will have to invent completely novel syntheses."

Scientists from different disciplines are currently working on this problem at CHEM | ampere. As its name suggests, the CHEM | ampere initiative's focus is on the interplay and interdependence between chemical processes and electrical energy. In addition to researchers from the fields of chemistry and physics, engineers from several universities and Fraunhofer institutes are also involved.

"We use CO_2-neutral energy in chemical processes and use carbon dioxide as a raw material." says Klemm summing up the vision of an ecologically sustainable chemical sector that the CHEM | ampere team is creating. The process energy can be generated from photovoltaics, wind power or geothermal energy. Carbon dioxide is a ubiquitous →

Prof. Elias Klemm

"We will have to invent completely novel syntheses."

Significant intermediate substances: under the leadership of Prof. Elias Klemm (right), the researchers convert carbon dioxide into formic acid, which then provides a basis for further syntheses.

→ and virtually unlimited raw material, which chemists can convert into intermediate substances such as formic acid or various alcohols, which will then form the basis for further syntheses.

This results in the usual range of chemical products, the only difference being that even if they were to be recycled in a waste incineration plant, they would still be CO_2-neutral as their basic material was extracted from the atmosphere. Even better, following incineration, the CO_2 could be washed out of the exhaust gas and recycled.

DECENTRALIZED CONCEPT

Nevertheless, CHEM | ampere is predicting a serious restructuring within the chemical sector. "Our concept is decentralized," Klemm clarifies and goes on to explain that conventional chemical factories are enormous and often require their own power plants. In contrast, renewable energy is generated in a decentralized manner, whether in wind farms or variously sized photovoltaic systems. At this time, even huge solar farms would not be capable of supplying a chemical plant with sufficient electricity, which is why the idea of the decentralized approach is to run individual process steps wherever there is a sufficient amount of "green" electricity or particularly high levels of carbon dioxide available. At CHEM | ampere, for example, the scientists are planning to use containers in with built-in production facilities for basic chemical substances, which could be installed at sites where a lot of CO_2 is produced, such as in cement factories.

The researchers are still working on a number of subprojects. "But," says Klemm, "we are already on the verge of merging these individual technologies into full processes." The objective, he says, is to be able to demonstrate a complete process so as to be able to convince industry stakeholders. The sector is not yet feeling much pressure, but this will change as CO_2 savings in other sectors improve at which point, Klemm hopes, the transition to a sustainable chemical industry could succeed. ⇥

CHEM | ampere's aim is to enable fundamental changes within the chemical sector.

Breathing life into the factory of the future

Procedures tested: members of the research team test new control approaches in the DC laboratory.

TEXT: JENS EBER

The ideal production facility of the future will be networked and will operate in a resource-saving manner, whereby people and the environment will be at the center. A research project at the University of Stuttgart is currently realizing key elements of this vision.

The traditional factory as we imagine it to be comprises production buildings, chimneys, warehouses and offices, and is surrounded by fences or walls. Apart from sharing the municipal water and electricity systems, it has very little to do with the surrounding companies or residential areas. The factory of the future, on the other hand – or more precisely, of a sustainable, CO_2-neutral future – will be networked beyond its own boundaries and will interact positively with other companies, the environment and the people around it.

For example, Germany's largest copper producer, the Hamburg-based company Aurubis, has not exactly been considered an ecological showcase in the past. The production process generates large volumes of waste heat, which for many years Aurubis had to use even more energy to cool. When the city began construction on the new Hafencity East district, they concluded a supply contract with Aurubis and the energy supplier Enercity under which the waste heat will provide the entire area with district heating. This heat is actually also CO_2-neutral because it is primarily generated through chemical processes. This will save several thousand tons of carbon dioxide per annum.

In Prof. Alexander Sauer's opinion, this collaboration between the city administration and the industrial sector is a successful example of the "open factory boundaries" principle. Sauer is head of the University of Stuttgart's Institute for Energy Efficiency in Production (EEP) and the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA). He also heads up the ultra-efficient factory, a research project funded by the state of Baden-Württemberg, among others, to help lead the industrial sector into a sustainable future.

RECONCILING EFFICIENCY AND EFFECTIVENESS

The ultra-efficient factory is attempting to realize the vision of a CO_2-neutral production facility and operates in symbiotic relationships with its environment. Sauer emphasizes that the concept creates a balance between efficiency and effectiveness, which means that this kind of factory consumes as few resources as possible and operates in as ecologically harmless a manner as possible. People and the environment are the central consideration in this paradigm. Not only will existing or planned factories be analyzed from the point of view of ultra-efficiency, but the plan is to also apply this approach in the development and planning of new industrial areas in the future. After all, the Greens and CDU in Baden-Württemberg also anchored the concept of ultra-efficiency in their coalition agreement concluded in May 2021.

Even before the participating researchers discussed their practical approaches with the respective companies, they identified five fields of action in which they see potential for improvement which included: energy, materials, emissions, personnel, and organization. In addition to using energy as efficiently and effectively as possible, utilizing materials as many times as possible and optimizing the recycling of residual materials, and ideally even redesigning production processes to reduce emissions, ultra-efficient factories should be organized such that they are flexible and capable of change, which would make them more resilient to changing framework conditions. According to the vision of the ultra-efficiency factory, administration and production staff should find "the greatest possible pleasure in their work", which will not only be achieved via more dynamic and greater →

Continuous testing: individual system components are also tested in the DC laboratory.

Dr. Sebastian Weckmann

"We're already surrounded by DC: most people just don't realize it."

→ self-determination in terms of working time models – Sauer also talks of a "feel-good factor" and adds that: "Employees should exit the factory healthier than when they entered it."

CREATING NEW SOURCES OF REVENUE

Whilst the idea of the ultra-efficient factory has been around for several years and is currently being refined, researchers at the University of Stuttgart are increasingly beginning to implement individual elements of the vision. For example, they are working with Alois Müller, a manufacturer of heating and ventilation equipment. The company has had photovoltaic systems installed on its production hall, to the east of Memmingen, which almost cover the entire roof. These systems not only power the company's operations but are also used to generate process gases on site in a decentralized plant that had to be purchased previously. In addition to such synergies, Sauer points out that the ultra-efficiency concept could open up new business areas or sources of revenue for companies.

The researchers are also working simultaneously on an ultra-efficient control center, where they intend to network and demonstrate different technologies and approaches, the goal being to create a combination of reality and virtual reality in which new approaches can be simulated in existing factories.

FEEDING ENERGY BACK INTO THE GRID

One of these approaches involves supplying factories entirely with direct current (DC) whereby the potential savings would be enormous. Dr. Sebastian Weckmann is working intensively on this subject at the EEP in Stuttgart. "DC is more energy efficient and can produce systems with a high supply quality at a more cost-effective price ," he explains. At the same time, mainly for historical reasons, the majority of contemporary industrial facilities are equipped with AC power grids because, in the early days of electrification in the late 19th century, there was a lack of suitable transformers to convert direct current. However, because the loss rate is lowest when the current voltage is high and AC transformers were already available at that time, AC current was widely adopted.

"Thanks to modern semiconductor technology, we can now also transform DC and transmit it over longer distances in a highly efficient manner," Weckmann explains. In addition, he points out: "We're already surrounded by DC: most people just don't realize it." DC is flowing everywhere – in laptops, energy storage units, e-mobility devices, and even on ships and airplanes. Numerous industrial production machines also use DC. The result is that AC first has to be converted in an intermediate circuit and before supplying the machinery in the form of DC. But, this "detour" results in power losses. "Our idea is to convert the electricity in a central location and only once for the entire factory," Weckmann explains Not only would this reduce power losses, but the energy could even be fed back into the grid when slowing down the machinery. It would also be much easier to integrate photovoltaic systems into the factory's power grid.

Industry stakeholders are already showing a lot of interest in the so-called DC factory: Weckmann estimates that the potential market for component manufacturers as well as machinery builders and plant construction firms to supply products for the transition to DC is much larger and includes the potential to convert existing machinery and plant that is currently fed off the AC grid to be able to take DC. He and his team are already working on the details of, for example, simplifying the integration of new components in a DC factory. ⇥

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Photos: University of Stuttgart/EEP, Fraunhofer IPA, Rainer Bez

THE OPTIMAL BALANCE

TEXT: JENS EBER

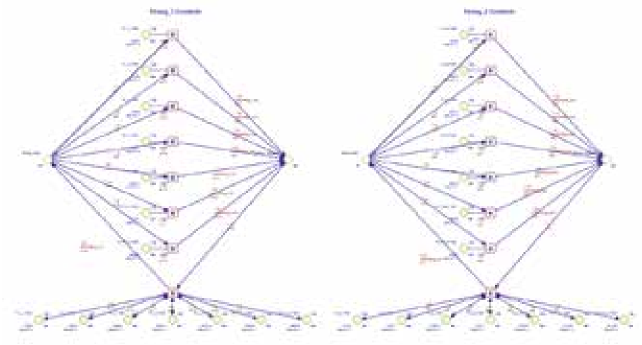
The University of Stuttgart's Institute of Machine Components is developing new ways to increase the service life of photovoltaic systems without increasing costs.

Electricity from solar energy is an important component of the energy transition and the field of photovoltaics is currently booming. In 2020 alone, photovoltaic systems with a total capacity of around 4.9 gigawatts were commissioned in Germany according to the Fraunhofer Institute for Solar Energy Systems ISE; this means that solar power experienced the strongest growth of all forms of energy. Around one in ten kilowatt hours consumed in Germany are already generated in solar modules installed either on ground-mounted systems, roofs or façades.

But, what is good for the environment and helps drive the energy transition is also beset with problems. Profits in the photovoltaic component market are low, so manufacturers need to produce them as cost-effectively as possible. Yet, at the same time, because of the low feed-in tariffs of just a few cents per kilowatt hour, customers – whether homeowners, industrial corporations or investors in free-standing solar plant – expect all elements to have the longest possible service life, as the investment only starts to pay off after some ten years or so.

Martin Diesch of the University of Stuttgart's Institute of Machine Components (IMA) is researching this area of tension. He heads up a team at the Institute, which is led by Prof. Bernd Bertsche, that is studying the durability of renewable energy generation systems. "We could simply oversize every component to increase their service lives," Diesch explains, "but that"would only make everything more expensive whereas the objective is to make them cheaper." That is why he and his team as well as other project partners from research and industry, are trying to find the optimum balance between durability and cost.

A photovoltaic system – comprising a greater or smaller number of shiny blue modules on a roof or in a field plus a few electronic components in the roof space or in some inconspicuous nearby building – may seem simple at first glance: the power is generated → silently and is emission-free. Yet, these systems are exposed to many more influencing factors than may initially be apparent. "It makes a difference, whether the plant is located in Germany or, for example, in the Sahara," Diesch explains.



Detailed data: simulation for a concept comparison of string states

Whilst extremely high levels of solar radiation totaling several thousand hours per year, such as is common in deserts, does result in a high electricity production output, it also places the components under an enormous stress. Operators in Germany can only expect an average of around 1000 kWh/kWp per annum during which their systems produce their maximum output. But even this is not free of component damage such as corrosion caused by the our much wetter climate.

The various components of a photovoltaic system are also susceptible to different kinds of defects and the impact caused by failure has a different severity level for each component type: if one solar module fails to work, it can be bridged and the surrounding modules would continue to supply power. If, however, the inverter that converts the generated direct current into alternating current and feeds it into the grid is develops a fault, the entire system will be paralyzed and will no longer produce power.

THE GOAL IS TO DEVELOP A NEW PERSPECTIVE

In one of the projects, the team is conducting research into inverters with the aim of increasing the reliability of the PV plant by testing components that have already been identified as critical for their potential service life. Kassel-based SMA Solar Technology AG, a major manufacturer of inverters, is also participating in this project. Random failures in electronic components are known to occur which is why a major degree of overdimensioning is the accepted norm. "We want to change that perspective," says Diesch, a reliability engineer. Another objective, he continues, is to give manufacturers access to detailed component data that they can then feed into their product development processes.

Researchers at the Reliability and Drive Engineering Department, which is headed up by Martin Dazer, have simultaneously created a simulation model for different PV application scenarios, which was an extremely time-consuming task due to the vast number of influencing factors and parameters. In addition, as Diesch explains: "Nothing at all is currently known about the service life and reliability of many components." There is simply not sufficient known about the precise sequence of the relevant failure mechanisms. Determining the service life of a component is also complex because typical operating periods of 10, 20, or more years must be "compressed" to gain an understanding in a reasonable amount of time.

The study is not only concerned with the potential failure behavior of individual components, but also with the resulting costs. A component that costs only a few euro, but which would put the entire system out of commission were it to fail, would potentially need to be dimensioned more robustly than parts whose failure has only a marginal impact. ⇥

Martin Diesch

"It makes a difference, whether the plant is located in Germany or, for example, in the Sahara."

Photo: Getty Images/Moment RF, image: IMA

FASHION THAT FITS

TEXT: MIRIAM HOFFMEYER

Taller, smaller, fatter, thinner: By no means do the standard off-the-shelf sizes fit everyone. Researchers at the University of Stuttgart are developing new bespoke manufacturing technologies that would still enable textile manufacturers to turn a profit.

An innovative approach: Prof. Meike Tilebein in the Textile 4.0 multifunctional laboratory at the German Institutes of Textile and Fiber Research (DITF)

PROF. MEIKE TILEBEIN

"Unfortunately, the textile industry is considered to be dusty and old-fashioned, but it is actually a driver of innovation."

Among the smart textile machinery and computer workstations, the changing room almost looks like something out of a museum. Immediately behind the entrance to the Textile 4.0 multifunctional laboratory of the German Institutes of Textile and Fiber Research (DITF) in Denkendorf near Stuttgart, one sees the dense, khaki-colored curtains between which stands a stocky plastic female-like figure, a good head taller than standard mannequins. If it were a human woman, she would struggle to find well-fitting clothes, which is a common problem, as Prof. Meike Tilebein explains: "Standard clothing sizes do not properly fit about 30 percent of the population."

An expert in strategic innovation management, Tilebein heads up the University of Stuttgart's Institute for Diversity Studies in Engineering (IDS) in addition to the Center for Management Research at the DITF and is fascinated by the opportunities that digitally networked development and production processes could mean for the textile and apparel industry: "Not only can one produce things in a better, more sustainable and more cost-effective manner, but completely new business models are also conceivable."

The production of a T-shirt in the Industry 4.0 economy begins in the body scanner. The seemingly old-fashioned changing room houses three laser columns with which a person can be scanned from head to toe in a matter of seconds. A screen immediately displays over 100 measured values – the basis for a digital twin. The virtual reality goggles in the lab then show how well this avatar would look in different sets of clothing. Hands and feet can be measured using a hand-held 3D scanner. Another device scans fabric samples and determines their structure and optical properties. The recorded data is then used to generate control algorithms for printing and cutting machines. Blue patterned blanks for a top are in place on the modern single-layer cutter.

Digitized production could make customized garments affordable for everyone in the future. The textile printing needed to create bespoke designs, such as T-shirts bearing the wearer's name, would not cost very much more. And last but not least, the new technology could facilitate the production of medical aids such as support stockings or pressure bandages, for which an accurate fit is particularly important. The DITF have already demonstrated their complete "Digital Textile Microfactory" at several leading trade fairs, showing everything from the body scanner to 3D design, printing and cutting to →

Virtual fitting room: VR glasses can be used to see how well certain clothes look on an avatar.

→ joining on a smart sewing machine. Because robots capable of handling textiles well don't yet exist, sewing still has to be done by humans. But the sewing machine in the multifunction lab can already read the QR codes printed on fabrics to automatically set the feed speed, stitch length and number of stitches.

Undergraduates in the "Engineering Cybernetics" program will be given the opportunity to use the laboratory to complete their project planning internship on questions relating to the Digital Textile Microfactory as of the winter semester of 2021/22. Meike Tilebein, who herself studied engineering cybernetics in Stuttgart, hopes to get students more interest in the textile industry: "Unfortunately, the textile industry is considered to be dusty and old-fashioned, but it is actually a driver of innovation." After all, many German textile companies that have survived the various crises and migration waves over the past decades are current market leaders in their respective specialties.

Tilebein also wants to encourage students to think in terms of business models during their project planning internship, to which end they would not only have to think about the technology, but also about the customers: "Not all great technologies make it to market," she says: often because people fail to recognize potential applications. Successful innovations are created on the basis of a diversity of perspectives."

The same systemic thinking that characterizes the field of cybernetics also shapes interdisciplinary research at the Center for Management Research. In collaboration with industry partners, the researchers are studying the entire textile value creation chain from development to the virtual showroom, one of their central questions being how digitalization could be used to make the industry more sustainable. For example, virtual models of garments and shoes could one day make the production of prototypes and the extensive sample sales collections redundant. "This is not a trivial matter," says Alexander Artschwager, project manager at the Center for Management Research and responsible for the DITF multifunction lab: "Producing a single T-shirt can use up to 5000 liters of water." →

→ The savings potential in the mass production sector is even greater. Tilebein believes that the use of these new technologies might make it possible for certain steps in the textile production chain to be relocated back to Europe, perhaps even to the inner cities, in which case, companies could initially produce garments in small batches and then rapidly order more according to demand. "Textile production would become much more demand-driven," she says A lot of the surplus production currently gets destroyed." This is also true of many return items. Trying on virtual garments could also go a long way towards solving this problem, as most items are returned because they do not fit or do not look as expected.

But could the digital acceleration of processes not also contribute further to the environmentally damaging "fast fashion" business model, flooding the market with even more clothing at even shorter intervals that would eventually end up in the trash again? The researchers are also studying these so-called "rebound effects". But Meike Tilebein is optimistic: "People won't be so quick to dispose of clothes that fit perfectly and look good." ⇥

Alexander Artschwager

"Producing a single T-shirt can use up to 5000 liters of water."

New directions: Meike Tilebein's team is developing ideas for digital optimization within the textile industry.

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Photos: DITF

Talent for an industry in transition

Profitable exchange: the GSaME also promotes networking among doctoral students.

TEXT: JENS EBER

The University of Stuttgart's Graduate School of Excellence Advanced Manufacturing Engineering (GSaME), which unites outstanding doctoral students and leading companies to their mutual benefit, recently celebrated the graduation of its 100th successful PhD candidate.

Conducting research into relevant, practice-oriented doctoral subjects, gaining valuable additional qualifications along the way and forging a network of contacts for one's professional future – that is the concept behind the Graduate School of Excellence Advanced Manufacturing Engineering (GSaME). It was founded in 2007 as a multidisciplinary doctoral program and was the first project to be carried out at the University of Stuttgart under the German federal and state governments' Excellence Initiative, the aim of which is to form links between cutting-edge research in the field of production engineering and the challenges of an industry in transition.

The participation of partners from the private sector demonstrates the industrial relevance of the research being conducted there. Around half of the projects by doctoral students are completed in collaboration with a company through which they get involved in → the development of new processes and products. "The idea is for the doctoral students to provide us with new findings that ultimately have practical applications," says Dr. Martin Lehmann, clarifying the practice-oriented approach of integrating research and development. Lehmann is responsible for the research network at Mann+Hummel, a Ludwigsburg-based filtration specialist, and has developed an appreciation for the collaboration with the GSaME from the perspective of an industry partner.

In addition to working on the scientific subject of their own research projects, doctoral students at the GSaME also take part in an interdisciplinary qualification program. Each research project is supervised by a thesis committee. PhD students also take part in regular status seminars, where they present their research as it currently stands. The program also includes a so-called complementary qualification in a field that had not previously been part of the respective course of study, as well as projects concerned with interdisciplinary issues that promote scientific and interdisciplinary collaboration.

Congratulations to Vitali Hirsch (front): the freshly baked PhD holder is shown here with the Head of the Examination Committee Prof. Georg Herzwurm, and GSaME spokesmen Prof. Bernhard Mitschang and Prof. Oliver Riedel

A strong network: the annual meeting of the GSaME in 2018

DEVELOPING LEADERSHIP QUALITIES

It was this breadth of qualification that also convinced doctoral student Katharina Dieterich: "I think it's great that I can continue my education whilst doing my PhD," she says, "that's a win for me." Dieterich's doctoral studies are about "Disruptive innovations – the prerequisites for breakthrough innovations, in particular an innovation culture as an enabler for product and process innovations in production networks." In her opinion, the opportunity to acquire both leadership and routine presentation skills, among other things, as well as to carry out in-depth research represents a great opportunity to prepare for future challenges in the professional world.

The statistic show that the GSaME is functioning successfully: the 100th doctoral student celebrated his graduation in March 2021. Vitali Hirsch earned his doctorate in collaboration with Daimler AG on "The data-driven identification of potential quality problems in complex assembly products." In excess of 550 scientific articles based on the research carried out at the GSaME have been published in journals or at conferences since 2007. GSaME graduates are currently participating in five spin-offs and 35 patents and patent families have been filed. It almost goes without saying, therefore, that the program has no trouble in recruiting interested participants.

"We not only want to train excellent scientists," says Dr. Thomas Ackermann, once a GSaME participant and now its scientific coordinator, "but we also want to train tomorrow's decision-makers." To achieve this, the Graduate School intends to place even more emphasis on teaching social, leadership and methodological skills than it already does.

Numerous companies, including some from the automotive industry, as well as plant engineering and special machine construction firms and those working in the field of semiconductor technology, have already come to recognize the appeal of collaborating with the GSaME. Martin Lehmann from Mann+Hummel sees the dual qualification in technical and management knowledge as one the GSaME's great benefits – for his company too. As they work in project teams within the companies, the doctoral students, with their eye for scientific detail, have been able to provide many interesting new insights. "The participants often introduce an entirely new set of perspectives."

CLOSE CONTACTS WITH PARTNER COMPANIES

As Prof. Bernhard Mitschang, spokesperson for the GSaME, explains: "The GSaME enables companies to screen potential new employees at an early stage." At the same time, he continues, the graduate program has created a strong network between the five participating University of Stuttgart faculties and the various partner companies. Many of the doctoral students establish lasting contacts among their own numbers: the GSaME Alumni Association currently has over 100 members. →

→ For many of the doctoral students, participation in the GSaME also serves as a springboard into a professional career. “In general, graduates who work on the collaborative projects are subsequently retained,” says Dr. Gabriele Erhardt, executive director of the Graduate School. The rate has dropped slightly since the outbreak of the Covid-19 pandemic, she continues, but industry support for the program continues undiminished. According to Erhardt, the pandemic has actually had some positive effects in other ways: “We currently have the highest publication rate per doctoral researcher since the GSaME was founded. Many new patents have also been filed.”

Mann+Hummel also views the GSaME participants currently deployed within the company as talents for the future, as Martin Lehmann explains. The Ludwigsburg-based company has hired five doctoral students from the Graduate School in recent years. “These included people with special technical qualifications that were otherwise lacking within the company,” says Lehmann, citing a further benefit. Several graduates have subsequently found a job within the company, although this is never a guaranteed outcome. “We’re always happy when there’s a good fit – if not, these people leave as highly trained individuals.” ⇥

THE GSaME in figures

The GSaME is home to over **30 professors** working in the faculties of design, production and automotive engineering, energy, process and bioengineering, economics and social sciences, computer science, electrical engineering and information technology, aerospace engineering and geodesy. The Graduate School is organized into **six research clusters** that combine the traditional production-related subjects with IT, management and sustainability. Together, the directors **of the six clusters** form the GSaME’s Board of Directors. The principle of a dual doctorate that has been realized in the GSaME was so groundbreaking in its development that the Graduate School received funding under the German federal and state governments’ Excellence Initiative in **2007** and **2012**. Having **received twelve years of funding** the program has been receiving support from the state of Baden-Württemberg since 2019.

Catherine Dieterich

“I think it’s great that I can continue my education whilst doing my doctoral degree studies – that’s a win for me.”

Prof. Bernhard Mitschang

“The GSaME enables companies to screen potential new employees at an early stage.”

Dr. Gabriele Erhardt

“In general, graduates who work on the collaborative projects are subsequently retained.”

Dr. Martin Lehmann

“The idea is for the doctoral students to provide us with new findings that ultimately have practical applications.”

Dr. Thomas Ackermann

“We not only want to train excellent scientists, but we also want to train tomorrow’s decision-makers.”

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Photos: GSaME, Sven Cichowicz

He who finds the faults

TEXT: Michael Vogel
PHOTOS: Sven Cichowicz

Junior Professor Andrey Morozov is conducting research into how to make cyberphysical systems more reliable, whereby he is using artificial intelligence to carry out autonomous troubleshooting.

In retrospect, career paths often look straightforward, planned in advance, or even inevitable. But the reality is usually very different. “As a youngster,” says Dr. Andrey Morozov, “you don’t actually have the information you would need to plan a career.” But although the computer scientist initially lacked a clear career plan, he was already aware during his studies that he wanted to work abroad. And he has achieved that goal: the 36-year-old Junior Professor has been working at the University of Stuttgart’s Institute of Industrial Automation and Software Engineering (IAS) since April 2020 under a six-year tenure-track scheme. During this time, the young scientist’s tasks include establishing a new professorship for networked automation systems and achieving predefined research and teaching objectives.

Morozov was born in Ufa, a Russian mega city about 500 kilometers from the Kazakh border and 500 kilometers in a different direction to Ekaterinburg or Kazan and dominated by the oil industry. “By Russian standards” says Morozov with a wink, “those places are considered neighboring towns.” After school in Ufa, he went on to study computer science and mathematics at the Ufa State Aviation Technical University. “My university had connections with the Institute of Automation Technology at TU Dresden,” Morozov explains: “That’s how I got the chance to spend time abroad. I also wrote my diploma thesis in Dresden with Prof. Klaus Janschek."

A FURTHER DEVELOPMENT OF THE DOCTORAL THESIS

During his studies, Morozov worked as a part-time student trainee at a financial company. “There I had to automate Excel scripts, which was pretty boring,” he says; “I certainly didn’t want to work in an environment like that later on.” After graduating in 2007, he first worked as a software developer in the research and development department of a Russian oil company. But the relationship between Morozov and the corporate world remained difficult, so doing doctoral degree studies, preferably abroad, struck him as a more interesting step. So he applied for a position at the TU Dresden under the Erasmus program and was accepted in 2009, then aged 24, but the position was only funded for 34 months, which is really rather short for a doctorate. But he made it, and ‚managed to hand in a draft of his thesis within that time. His thesis was on “The reliability of mechatronic systems”, which continues to play a significant role in his current research. In his thesis, he outlined a model for detecting faults in cyberphysical systems in which software, electronics and mechanics are closely coupled, whilst the systems as a whole are also networked. Production robots are a good example of this. When fault develop in such complex systems, it is often difficult to understand what went wrong, hence the need for sophisticated fault detection methods.

PROJECTS WITH DLR AND ESA

Morozov earned his doctorate in 2012 and ... found himself frustrated. “I had no idea where to go from there,” he recalls. He applied to various companies in Europe, “but either I wanted to work for them but they didn’t want me, or they did want to take me on but I had second thoughts.” It was a lucky stroke when he was offered a position on a project in Dresden, which had to do with autonomous robotic space vehicles. The project was →

Autonomous fault detection: Morozov with the "KrakenBox", which he and his team developed

Dr. Andrey Morozov

> "Basically, we're combining traditional fault analysis approaches with artificial intelligence."

→ funded by the German Aerospace Center (DLR) and the University of Stuttgart was the project partner. "I had even been to Stuttgart several times when I was working on my PhD," says Morozov. This was followed by another project, this time with the European Space Agency (ESA), which again involved model-based fault detection and analysis. "It was really my project – my idea, my field of study."

Morozov established his own research group as a postdoctoral fellow in Dresden, which focused on the model-based analysis of safety-critical mechatronic systems. He eventually decided to pursue an academic career in 2017 so an extended stay in the USA seemed appropriate. He went to the University of California in Los Angeles, where he made some lasting contacts. "We still collaborate today." Morozov remembers that plans for his visit to the USA were first hatched at a conference and emphasizes the importance of interpersonal exchanges that take place at such meetings, especially for young researchers.

Another conference also helped Morozov with his current position. "On the evening of that conference in Italy, I and some colleagues visited a bistro, where we just chatted about this and that," he says: "Then someone mentioned the tenure track and I asked them about it. 'It's worth looking at – check it out,' they said." Well, no sooner said than done! Morozov applied for two junior professorships in Germany in 2019, one of which was the one in Stuttgart.

He arrived to take up the junior professorship just as the first Covid-19 wave hit, which prevented his wife and three children, who had stayed in Russia while he was relocating from Dresden to Stuttgart, from being able to enter the country as all direct flights had been canceled. Eventually, the couple did find a way: his family landed in Geneva in September 2020 and traveled on from there to Stuttgart.

THE "KRAKENBOX" AUTONOMOUSLY DETECTS FAULTS

Morozov currently employs two doctoral students in his research group, and two more are ready to start. The so-called "KrakenBox", which autonomously detects faults in industrial cyberphysical systems is among the team's initial results. "What we do," Morozov explains, "is to identify those places within the system where faults are apt to occur and then train a neural network that can then detect the respective fault conditions with no further intervention from us." To achieve this, a demonstrator first reads the data from the virtual sensors from a simulation before going on to analyze a realistic simulation of two robotic arms. "Basically, we're combining traditional fault analysis approaches with artificial intelligence." ⇥

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DR. ANNETTE ARNOLD

SUSTAINABILITY AS A MATTER OF PRINCIPLE

INTERVIEW: Andrea Mayer-Grenu

Climate change, digitalization, the consequences of pandemics – the major challenges of the industrial sector do not stop at medium-sized enterprises. Dr. Annette Arnold, Managing Director of Alfred Arnold Verladesysteme GmbH & Co. KG and an alumna of the University of Stuttgart, discusses how she tackles them whilst simultaneously making the business more family-friendly.

Photo: Private

DR. ANNETTE ARNOLD

Annette Arnold studied mechanical engineering at TU Darmstadt and completed her doctorate at the University of Stuttgart's Institute of Mechanical Handling and Logistics (IFT) between 2005 and 2007. She has held various positions at Alfred Arnold Verladesysteme GmbH & Co. KG since 2004, and has been Managing Director there since 2017.

Dr. Arnold, how does one position a traditional family business to meet the challenges of the future?

ANNETTE ARNOLD We've been very conscious of the challenges posed by climate change for a long time, and we began actively addressing them very early on. I joined the company at the same time as I began my doctoral studies about 16 years ago and, after graduating, I was given the opportunity to manage the construction of our new company building, Stuttgart's first EU-certified "green building". Our fleet already includes two fully electric vehicles. And all this can only be a start.

Our vision going forward, for example, is to work in a holistically sustainable way whilst simultaneously reshaping the market segment in which we operate through continuous innovations to provide users with solutions that will ensure the best possible efficiency levels, safety and sustainability. Not a year goes by without our successfully launching new products and details for the loading zone Many other discoveries remain to be made thanks to technological progress and changing framework conditions.

What challenges is Alfred Arnold Verladesysteme GmbH currently facing?

AA Like most people and companies, the Covid-19 pandemic has presented us with some hitherto unforeseen challenges. Our cross-border business in particular has been severely impacted by entry restrictions and quarantine regulations and we are still feeling the consequences in supply chains and assembly operations among other things.

We are simultaneously struggling to cope with the commodity escapades on the world market: whether it's foam, steel or electrical items, we are feeling the pinch of shortages everywhere as well as of such huge price increases that many things will have to be completely redesigned. Reliable cost and delivery time planning is a thing of the past.

What role does digitalization play in this situation?

AA The fact that we had already made good progress in the digitalization process prior to the pandemic has helped a lot. For example, all of our installation engineers already → had digital access to our internal knowledge base and collaboration tools, so we were able to spontaneously expand our remote collaboration activities. Whenever we implement innovations to address some urgent contingency, we do so in such a way that we can continue to use them over the long term, so, the digitalization of our work flows is now even more thoroughgoing, which benefits process transparency and speed. It's a never-ending process.

The turbulence that is currently affecting the supply of raw materials also necessitates new controlling scenarios in procurement. We have to be extraordinarily flexible to be able to respond to these disruptive changes, and the better our automated data analyses and forecasts, the easier it is to do so. But the associated additional effort and cost of data maintenance is enormous.

Arnold Verladesysteme is also very active in the field of research and development. What projects are you currently working on?

AA Our priority at this moment is sustainability. We have always focused on durability and reparability, but to make significant resource savings and "go green," we will be faced with new issues.

For example, I led a research project many years ago in which we completely re-conceptualized the loading zone and presented all such tasks as lower body protection for trucks, truck stabilization and positioning in all three axial directions within a new overall solution, which saves time and resources and increases safety. This research, which was funded by the German Federal Ministry for Economic Affairs and Energy (BMWi), earned me the honor of being picked as one of the TOP 5 researchers at the 2013 German Future Prize event.

Yet not all users are able to implement this comprehensive solution, so we are working on the provision of sustainable responses for all detailed point solutions. →

Dr. Annette Arnold

"The desire to pursue personal goals that contradict stereotypical roles often takes courage."

→What expertize that you gained during your doctoral research at the University of Stuttgart flows into your current work?
AA My doctoral thesis was about the field of logistics, so many aspects of it are naturally reflected in my current work. But, it seems to me that the mindset that one develops during such an endeavor is more important than the specific content: it's about learning to approach a complex problem in a flexible manner and from many angles, and to cultivate a sense of patience and perseverance in the full knowledge that solutions will not be found overnight. These are the experiences that help shape one's later work.

Despite many programs and initiatives, women continue to be underrepresented in engineering careers: what is the situation at Arnold Verladesysteme?
AA Half of our staff members are male and half female, but that's coincidental to some degree. However, I specifically encourage female students to work in our company. We generally do a lot to help our employees – whether mothers, fathers or family caregivers – to reconcile family life and work. Flexible work schedules and dependable working hours are both key to this. Aculture of being seen to be present outside of regular working hours has been out of vogue for many years now: everyone can arrive at the daycare or school on time, turn up punctually for a private appointment or pursue leisure activities without having to fear disadvantages in their professional career development. Experience has shown that this is extremely important when it comes to the compatibility between the different areas of life.

You have mentored female students and doctoral candidates at several universities, including the University of Stuttgart. What advice do you give young women?
AA During the mentoring program I became familiar with the variety of long-term dreams and life situations of many young women. It seems particularly important to me that women should clarify the fundamental questions for themselves: who am I, where do I stand, where do I want to go? After that it is not usually so difficult to find the way there. The desire to pursue personal goals that contradict stereotypical roles often takes courage: the more individual and/or ambitious the goals, the more challenging the path to achieving them can be but that is precisely the point at which one mustn't lose faith in oneself. People who carry on in the face of adversity and actually achieve their goals usually live very happy lives as well as serving as role models for others.

As an entrepreneur, what would you like to see from science?
AA Knowledge should be more freely accessible. I'm concerned about the commercialization of knowledge – if individual ideas can only be used by individuals, then that hinders progress. Small companies would benefit hugely from financially independent research that doesn't rely on private sector income in the form of contract research or patent rights, as SMEs can often not afford the necessary basic research, which excludes them from certain developments right from the outset. If the knowledge gained through publicly funded research were made accessible to all people and businesses, we would all have made much more progress by now. ⇥

DR. ANNETTE ARNOLD

"We have to be extraordinarily flexible to be able to respond to these disruptive changes."

University of Stuttgart

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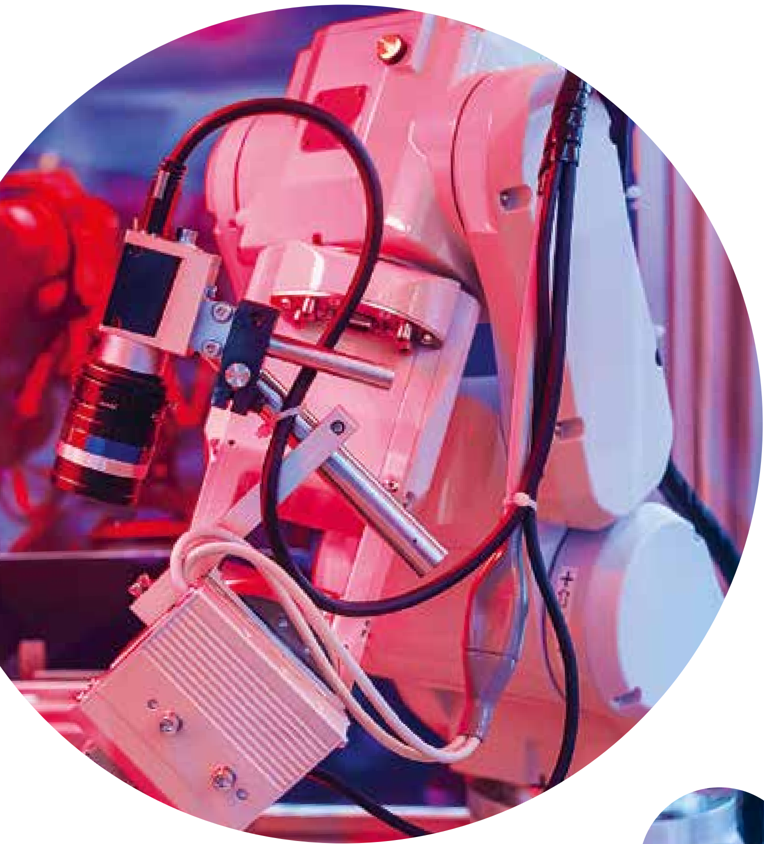

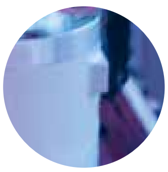

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