EEMCS

Multi-annual plan

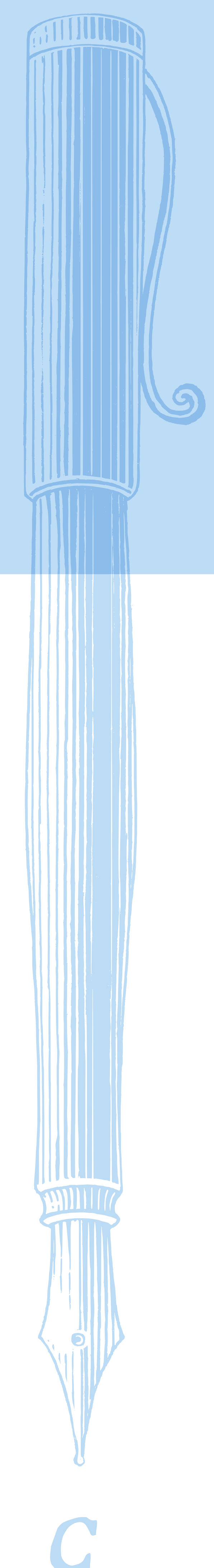
An exploration of the positive societal impacts that will be enabled in the years ahead thanks to science and technology from the Faculty of Electrical Engineering, Mathematics and Computer Science.

GET INSPIRED

TU Delft

Outline

'I hope that this multi-annual plan will inspire you'



Lucas van Vliet
Dean of the Faculty of Electrical Engineering, Mathematics and Computer Science

Dean's preface

From my office window, I'm looking out on the brand-new Echo building where our students are already studying and collaborating in state-of-the-art facilities. Further along the Mekelweg are other recent additions to the TU Delft campus – the Electrical Sustainable Power lab and the DelftBlue supercomputer. These new facilities highlight our ongoing transformation of the Faculty of Electrical Engineering, Mathematics and Computer Science (EEMCS).

Transformation is the common thread running through our faculty's multi-annual plan. Our main research themes involve transformations in the digital, energy and health domains. Another transformation is also important to us – strategic autonomy for the Netherlands and Europe in the area of critical technologies. Together, all of these transformations inform our exploration of priorities and our dreams for the future.

We want to deploy our research expertise to achieve positive societal impacts. For example, how can we ensure our cyber security in a world that is digitising fast? How can we design the multimodal energy system of the future? The solutions to many complex challenges like these rely on advances in electrical engineering, mathematics and computer science.

Several key enabling technologies are helping us to achieve our ambitions. Our faculty is the engine of artificial intelligence (AI) developments on the TU Delft campus. We are deeply involved in next-generation communication and sensing technologies, as well as unconventional computing paradigms. As we develop each new technology, we commit to the highest standards of accessibility, security and equity. In the years ahead, we will increasingly focus on how technology impacts people.

In the meantime, our graduates are in higher demand than ever before. As clichéd as it may sound, it really is our duty to train the engineers of the future. This means we should not only teach them skills within their field, but we should also let them experience how they can use those skills to solve and explain actual problems. We want to embrace new educational formats in which students confront real issues, inspired by priorities such as the UN Sustainability Goals. We have an excellent position in online education, and that can further reinforce our campus-based activities.

'Proudest of all I am of the people that make up the faculty'

What makes me proudest of all are the people who make up our faculty: our community. In the coming years, we will raise the bar further across talent appreciation, diversity and inclusivity. As we support individual staff and students to become the best versions of themselves, we also want to empower teamwork. I therefore close with the hope that this plan will inspire you. Whatever your background, or role, you have much to contribute to the transformations described in this multi-annual plan.■

Mission and vision

Vision

We believe in a technology-driven approach, contributing scientific breakthroughs and technological innovations that can address societal challenges in a global context.

Mission

To perform cutting-edge research and provide a stimulating environment for education and training of responsible engineers in electrical engineering, mathematics and computer science – resulting in revolutionary technologies and novel computational techniques.

Research themes

Research at EEMCS focuses on developing novel, sometimes revolutionary, engineering solutions and technologies. We seek to push the boundaries of scientific knowledge, conducting fundamental and innovative research in computer science, mathematics and electrical engineering. EEMCS researchers are both curiosity-driven and application-inspired, working together to provide innovative, responsible technologies for societal challenges. Themes are broad, spanning health and wellbeing, the energy transition and the transition of our digital society. We also approach a number of cross-border key technology areas in an interdisciplinary way, such as communication and sensing, artificial intelligence and unconventional computing/quantum technologies. Next to the overarching faculty themes, other themes coexist within the departments such as cyber security, semiconductors and agro.

> 'The faculty is proud of the curiosity-driven research'

Cooperation is flourishing, and is constantly expanding with national and international partners. In the coming years, we will continue to work on a number of new research initiatives. For example, a widely supported programme for Artificial Intelligence involves various ICAI labs and an extensive long-term programme via NWO called 'Robust'. In order to create a better critical mass in the outside world, we focus on larger consortia and more coordinatorships, so that knowledge, expertise and resources are used more efficiently.

Large programmes have also been set up with many important players in the fields of energy transition; quantum and unconventional computing; and communication & sensing. These often involve public-private partnerships with other universities and governments. A more intensive response to initiatives arising from the Chips Act of the European Union will also be worked out in the coming period.

In recent years, the faculty has been able to significantly grow - with larger projects, longlasting partnerships, collaborations with leading universities and the development of eco-systems - which we will continue in order to maximise our impact on society.

Cross-border collaboration is becoming more important next to the best practices we already have within our Delft AI labs and the Convergence program. These types of collaborations will further evolve.

The faculty is proud of the curiosity-driven research through e.g. personal grants obtained from various researchers, but this is still an area where we can improve. Obtaining such personal grants is positive for the reputation of the researchers involved and for the faculty in general, so in the years ahead we will be focusing on increasing the number of personal grants and actively supporting researchers at various stages of their career. ■

Energy transition

The energy transition is one of the largest global challenges of our time. A key aspect is replacing fossil fuels as primary energy sources with renewable energy sources (RES) such as solar and wind energy. The consequence of this radical change will be an accelerated electrification of society. Electricity will become a backbone of a multi-energy system with natural gas, hydrogen and heat as additional useful energy carriers. Several large-scale power plants will generate the electricity, and will be joined at a fast-growing pace by many small-scale distributed sources. The variable nature of RES challenges energy supply security and stability, and the transition will therefore have an unprecedented impact on the design and operation of the power grid, amplified further by the electrification of transport, heat and industry sectors.

AMBITIONS

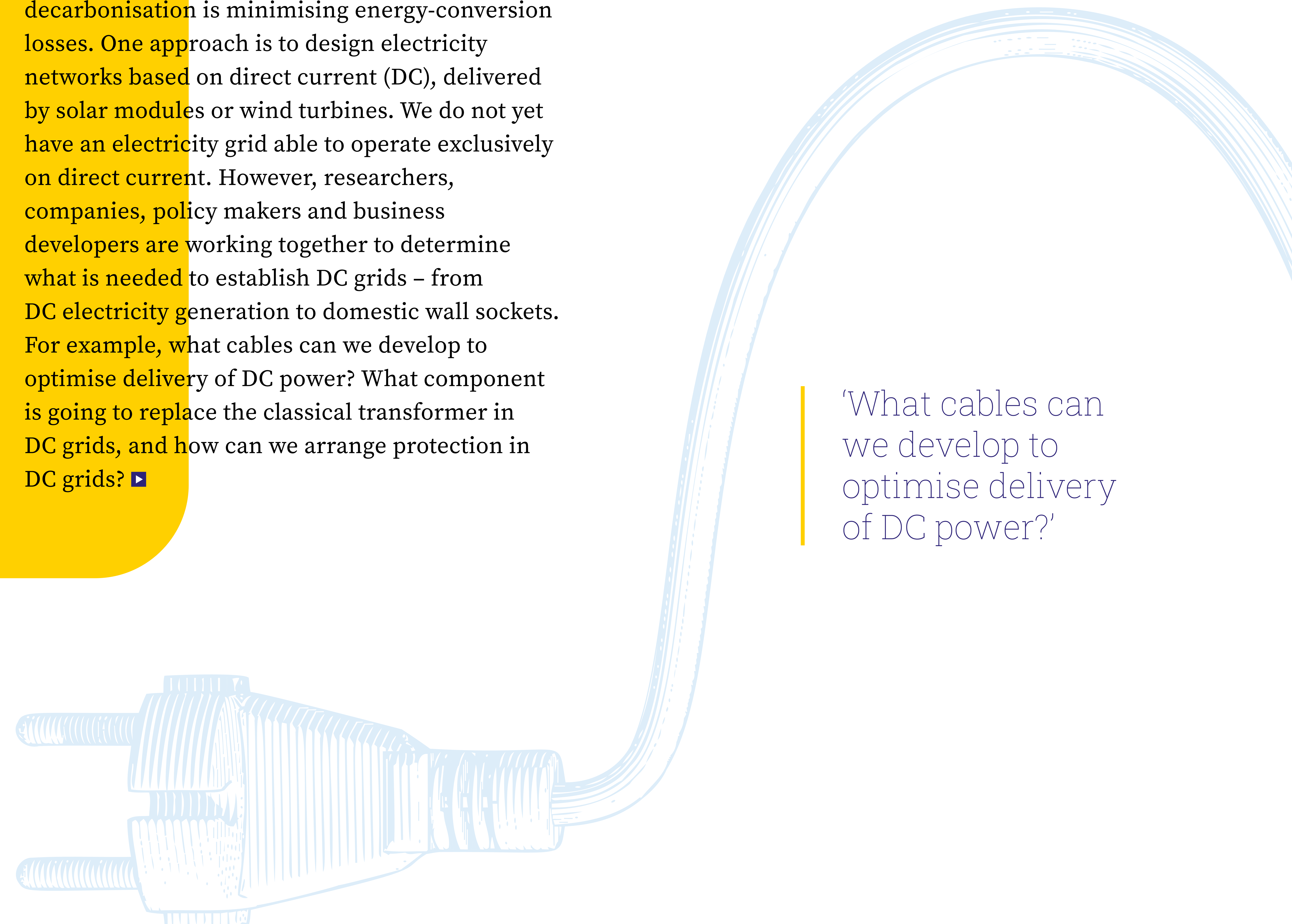
- *System integration of renewable energy sources*
- *A flexible and resilient power system, prepared for an uncertain future*
- *Intelligent, invisible and circular PV building blocks*
- *Community (DC) microgrids for smart cities, including e-mobility (electrical vehicles)*
- *Sustainable Energy hubs with hybrid storage (hydrogen, heat)*
- *Sustainable transport (railways, metro, tram) and transport electrification (ships, aircraft)*

Research challenges

Decarbonising society

Our research focuses on accelerating the substitution of fossil fuels by renewable energy sources and storage. In doing so our vision for the future is to make renewable energy sources more attractive to society. For example, we can integrate PV modules stealthily into the built environment, by having them communicate intelligently with each other and by making them circular. Another example is our research in lightweight and flexible thin-film solar foil, which can be applied in countless and unique ways – all the way from integrating it into traditional roof tiles through to creating large-scale solar parks that reduce the price of our electricity.

Another important topic related to decarbonisation is minimising energy-conversion losses. One approach is to design electricity networks based on direct current (DC), delivered by solar modules or wind turbines. We do not yet have an electricity grid able to operate exclusively on direct current. However, researchers, companies, policy makers and business developers are working together to determine what is needed to establish DC grids – from DC electricity generation to domestic wall sockets. For example, what cables can we develop to optimise delivery of DC power? What component is going to replace the classical transformer in DC grids, and how can we arrange protection in DC grids?



> 'What cables can we develop to optimise delivery of DC power?'

Another important decarbonisation step involves the electrification of society using renewable energy sources. We focus on electrification of both energy-intensive industries and e-mobility. DC-microgrids are preferred for charging vehicles via direct use of solar power. We study ways to use induction charging systems for electric vehicles by designing and placing coils below the road surface that wirelessly radiate power with high efficiency to vehicles above them. In order to increase flexibility of energy supply, we can allow batteries of electric vehicles to become mobile energy storage units and an active part of DC microgrids. Decarbonisation of transport (railways, metro, tram) is achieved by powering with sustainable energy along with storage to capture the energy from braking. Another important step meeting future challenges is transport electrification (electric ships and electric aircraft using sustainable fuels).

Decentralisation

A major turnaround is required to make the move from fully centralised power generation and control to more distributed power generation and the decentralised control of future multi energy-carrier grids. An important step is to give ‘prosumers’ an active role in the energy system. Think of combining a house’s solar panels with an in-home battery and a smart charging station that charges an electric car outside of peak hours, to mitigate peak load of the electricity grid. In the near future, our electricity and heat will be provided by a hybrid energy system based on variable RES and controlled by smart algorithms that include micro-cogenerators (combining heat and power); adaptable heat pumps; and electric cars – all contributing to energy system flexibility. Energy hubs with renewable energy generation and hybrid energy storage will help to supply heavy loads such as ultrafast charging stations, for example for heavy duty vehicles.

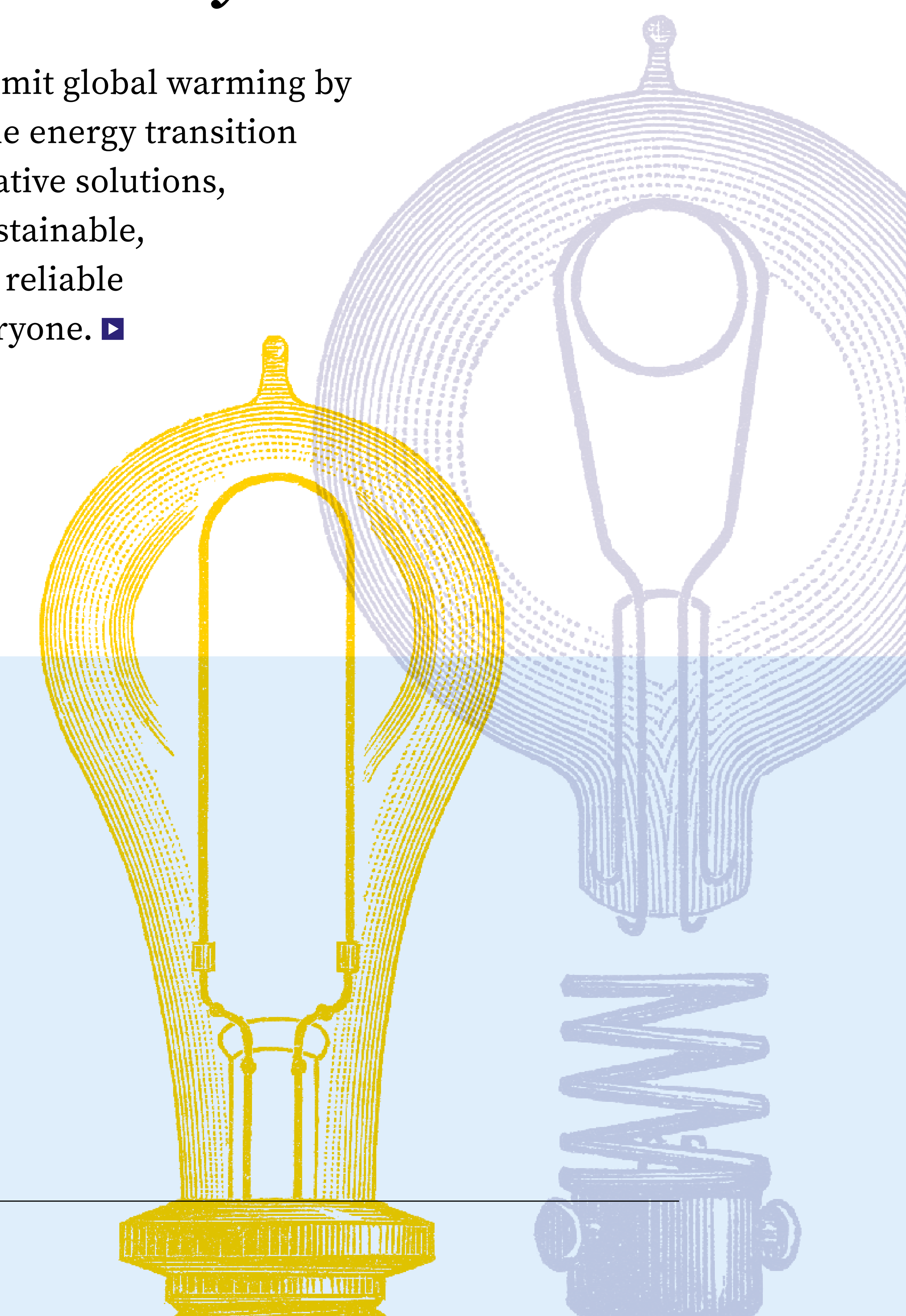
> ‘We focus on electrification of both energy-intensive industries and e-mobility’

Digitalisation

The energy transition towards sustainable energy will result in a more complex energy system using many new technologies and components. These include solar modules, wind turbines, power electronic inverters, and electric cars. Predictable energy consumption and generation is replaced by weather dependent generation, with millions of active prosumers and a faster, dynamic and less resilient electricity system. Maintaining reliability and stability requires intelligent infrastructure and digitalisation. The future energy system will use data extensively, for better and faster decisions in a dynamic system where all users can be active players, contributing to sustainable and reliable energy. Digital transformation, autonomous and collaborative assets, cyber security and machine learning are just a few topics within system digitalisation. For example, we are developing intelligent solar modules that will communicate with the local environment in order to maximise energy yield. We work on advanced numerical models and mathematics to understand, design and optimise the power system of the future. We use supercomputers to create digital twins of the Dutch electricity grid, and study how to react to physical failures or cyber-attacks within milliseconds. We are building an energy transition solution platform where society’s expectations and cyber reality come together.

Impact on society

Our aim is to limit global warming by accelerating the energy transition through innovative solutions, resulting in sustainable, affordable and reliable energy for everyone. ▪



Innovation

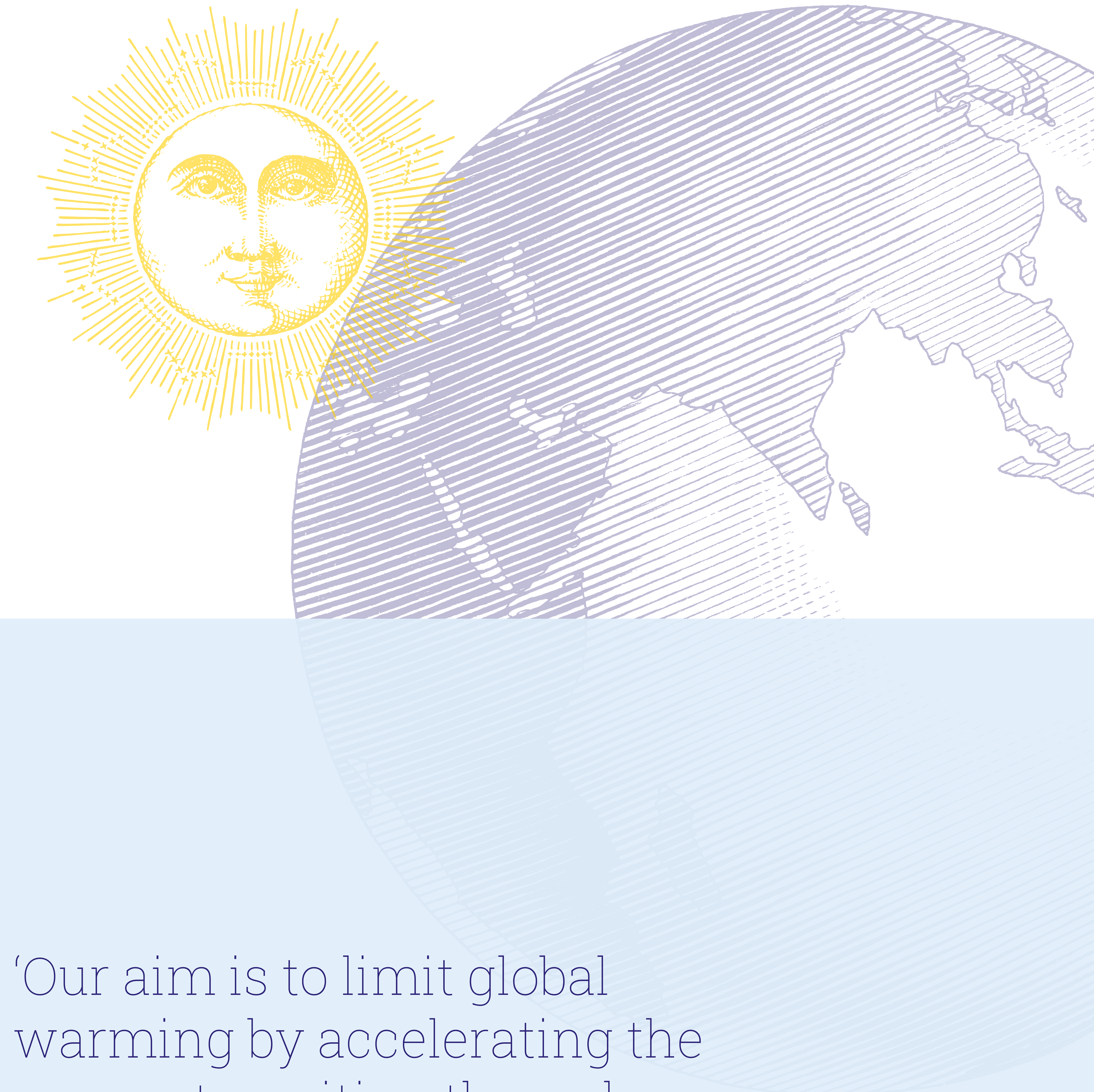
The focus is on large impactful projects and longlasting partnerships (gravity proposals, research infrastructure), carried out with major players in the energy transition. The combination and interchangeability of electricity, hydrogen and heat are important in solving the major challenges.

- **Strategic collaborations**
  - Grid companies such as Transmission System Operators (TSOs) and Distribution system operators (DSOs)
  - Testing, Inspections & Certification organizations
  - Power electronics companies
  - Electric power generation
  - e-Mobility and charging infrastructure
  - Knowledge infrastructure (AMS Institute, TNO)
  - Government, municipalities

- **Convergence**
  The digital transformation is irreversible and rapid, and has changed much of the past decade. Digitalisation offers great opportunities as well as big challenges, and there is currently a global race for leadership in the field. Focusing on a knowledge cluster that can resolve socio-economic, security and sustainability problems, with the help of AI, is essential for our country. Within the AI, Data and Digitalisation theme of ‘Convergence’, the sub-theme ‘Energy and Sustainability’ is closely linked with the activities of our EEMCS theme ‘Energy Transition’.

- **Research Infrastructure**
  - ESP lab
  - Control room of the future
  - TU Delft PV Technology Centre
  - DelftBlue supercomputer
  - The Green Village

- **Research topics**
  - Photovoltaics, photovoltatronics,
  - Energy conversion: power electronics and electro-mechanics
  - Reliability of power electronics
  - Design & operation of the future power system
  - Microgids, hybrid AC/DC grids
  - Storage: batteries, hydrogen
  - Digitalisation, AI, machine learning
  - Protection, resilience and cyber security of power systems
  - Integration of energy networks ■



> ‘Our aim is to limit global warming by accelerating the energy transition through innovative solutions, resulting in sustainable, affordable and reliable energy for everyone’

Responsible digital technology

The question is not when we will have a digital society - because we already have one. The question is how to organise it as well and as responsibly as possible. The digital society is all around us, in anything from the form of algorithms that determine which messages you see through to self-acting robots that sweep the seabed and use machine learning to distinguish between plastic and seaweed. Although it may not be apparent to everyone, digital applications are changing the world: they are making it cleaner, more sustainable, more just, safer, more inclusive and healthier. But there are also threats in the areas of privacy, safety, cybersecurity and inequality.

At TU Delft, scientists are working with engineers, businesses and the government to achieve a responsible digital transition. We are working on technologies that facilitate the digital transition – from algorithms and artificial intelligence to robots and the quantum computer – while pioneering how these technologies enable a better digital society. That digital society will monitor what makes us human and help to keep us healthy. It will be more fair and inclusive, and will help to build cities and ports sustainably and safely, to accelerate the energy transition and to combat climate change.

AMBITIONS

- *A responsible digital society*
- *Broad access to information*
- *Making products and services intelligent*
- *Security and privacy (also in the quantum computer era)*

Research challenges

Small liveable cities

Safety
A focus is placed on how technology can provide solutions to privacy and confidentiality concerns, by building an algebraic crypto & information society and via distributed trust.

Research directions for social media on socially relevant topics
Important elements are fair algorithms (causality) and the methodology for collecting data and processing it into meaningful information. Interactive visual analytics for complex systems will also be addressed.

Making products more intelligent
Our research focuses on using hybrid intelligence that combines the strength of AI with the intelligence of humans. We look at value-added AI that incorporates human values and societal norms, and which monitors and protects the health of the society. We also focus on conversational agents for explaining AI, using AI to analyse AI data, testing techniques for AI systems and dependable IoT.

Impact on society

We will strive to deliver economically and socially responsible and reliable (AI) solutions. These technologies contribute to the themes of energy transition/climate action and health. At the same time, we are educating people who can weigh up commercial goals but who always keep social responsibility aspects in mind. ■

> ‘Our research focuses on using hybrid intelligence that combines the strength of AI with the intelligence of humans’

Innovation

- **Strategic collaborations**
  - Computational social science
  - Fintech
  - Companies in a digital transition
  - Ministries and or municipalities
  - Societal institutions - such as ‘Koninklijke Bibliotheek’
- **Research Topics**
  - Trustworthy AI
  - Digital dependability: testing, reliability, safety, security
  - Blockchain
  - Cyber security

The average life expectancy in Europe continues to rise, and demand for care services will continue to increase in years ahead, as will their cost. We want to live longer in good health, yet there are fewer and fewer people who can provide care. A healthcare transition is needed, with an increased focus on the design and implementation of miniaturised biomedical systems for precision medicine, personalised care and healthy lifestyle maintenance. This involves the design of both in-vivo and in-vitro devices and systems, along with advanced imaging and diagnostic instrumentation.

The technological challenges are miniaturisation, accuracy and reliability, energy efficiency, biocompatibility, manufacturability and cost reduction. Addressing health and wellbeing means anything from material research and technology development through to device and circuit design, signal processing and system implementation. It also includes artificial intelligence in the operating room (e.g. for surgery training) and bio-informatics to identify risk genes. The central challenges here involve the analysis of massive volumes of health, treatment and genomics data. This includes personal lifestyle data, medical imaging data, and a range of multi-modal molecular data, as well as the (cyber)security and privacy aspects of health data.

Health and wellbeing

AMBITIONS

- *Accessibility and affordability (reducing the health gap)*
- *Disease prevention (early screening and diagnosis) and healthy lifestyle*
- *Precision treatment and cure (minimally invasive, patient-specific, closed-loop operation)*

Research challenges

Drug development assistive technology
Such as single-cell analysis, spatiotemporal patterns and tissue modes using flexible and customised 'Organs on a Chip' platforms

Prevention and early diagnosis
Research in this area is extensive and includes data-driven medical care and prevention via data analysis and AI (injury, illness); detection by using ultrasound, 3D trans-esophagal echography (TEE) or low-field magnetic resonant imaging (MRI); and techniques for neuro-related diseases, brain imaging, and cardiac arrhythmia (incl. Atrial Fibrillation).

Wearables, implantables, catheters and probes
Providing technology for the successful monitoring, diagnosis and treatment of many diseases and disorders. Techniques that we research include smart catheters, flexible implants, transcutaneous ultrasound neuromodulation, neurostimulation and autonomous vital sign monitoring.

Digital technologies to combat ageing problems
Many different areas such as mathematical modelling of biological phenomena; computer and behavioural support systems for mental health; brain signal processing techniques; crowd science for finding a cure for tinnitus; speech processing for hearing aids and cochlear implants; and the protection of privacy-sensitive information.

Smart robots to reduce the workload of the nurse

Application of Network Science methods to virus spreading and brain modelling

Impact on society

We strive to provide advanced diagnostic tools for precision medicine and affordable personalised monitoring and patient management solutions based on AI – contributing to a sustainable healthcare system for all.

Innovation approach

- **Strategic collaborations**
  - Medical Delta (ErasmusMC, Erasmus University LUMC, Leiden University)
  - NeuroTechNL
  - Health.4TU
  - University Medical Centers, (teaching) hospitals, and medical centers of expertise
  - Medical equipment and health-tech manufacturers
- **Convergence**
  - Within the convergence theme 'Health and Technology', we focus on the subtopics lifelong health, early diagnostics, and individually tailored precise medical treatment.
- **Research infrastructure**
  - Else Kooi lab
  - Biosonic lab
  - Wetlab
  - Biolab (in the making)
- **Research topics**
  - Organs on a Chip
  - Neurotechnology and brain imaging
  - Bioelectronic medicine/ electroceuticals
  - Reducing cardiac arrhythmia
  - Modelling and control of virus spread

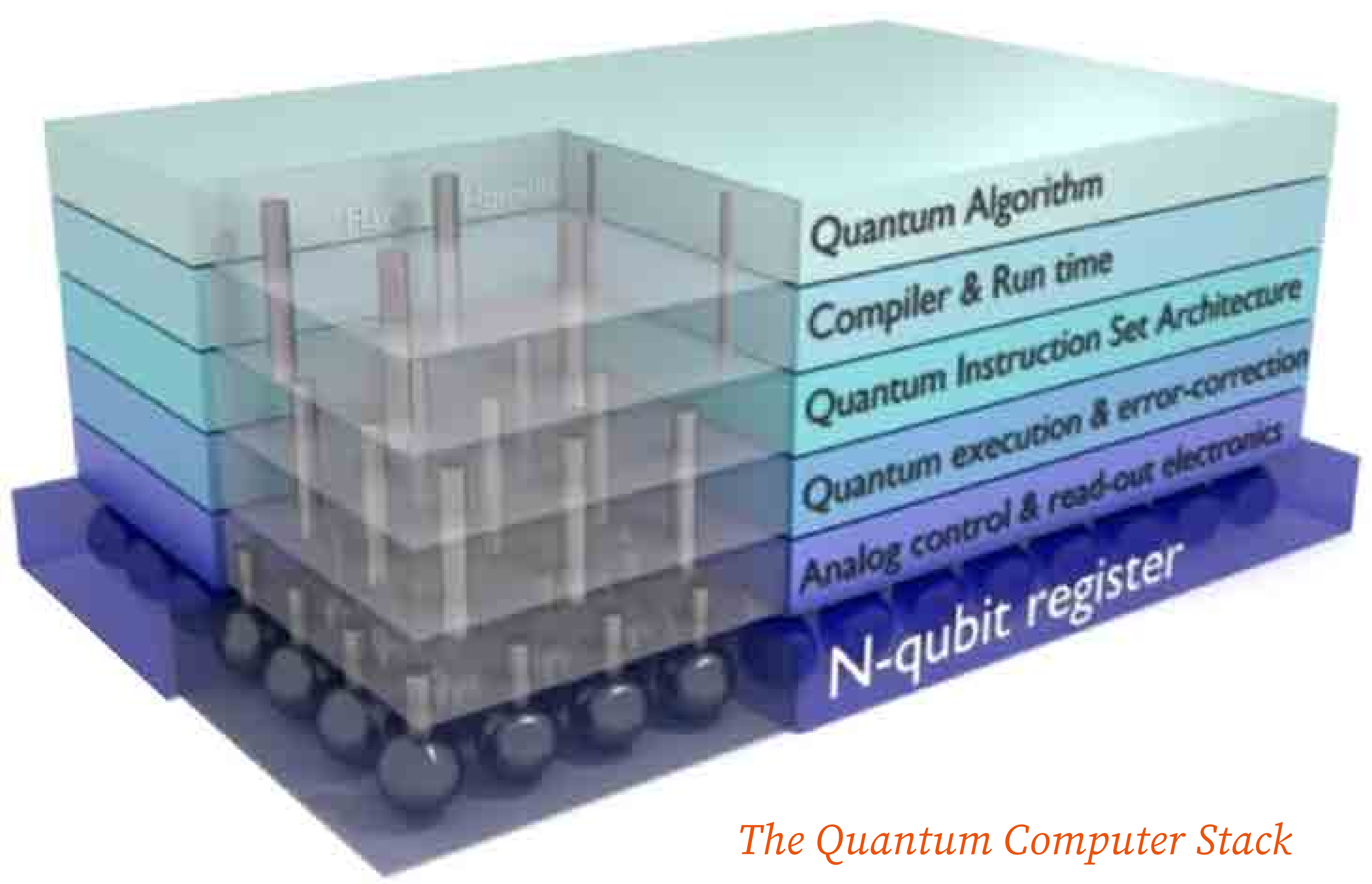
Unconventional computing | quantum technologies

Unconventional nanoelectronics promises an exponential speed increase in several practical computational problems, and an inherently safe internet. We are working to enable new computing systems that use different physical modalities for processing and communication, bringing benefits to most of today's systems. For instance, quantum computers exploit quantum effects, such as superposition and entanglement, for computation, sensing and communication. Other emerging technologies are memristive devices used for computation-in-memory and bioinspired neuromorphic computation, as well as electron spins used for spin wave computing in green ICT.

Current research focuses on developing new concepts at the levels of device, circuit architecture, processing, communication, integration, software and algorithmic/protocols. These will enable the computing paradigms above and demonstrate their potential for greatly improved performance in generic or specific applications.

AMBITIONS

- *Design, prototype and demonstrate the potential of quantum computers in long lasting partnerships*
- *Design, prototype and demonstrate +100X energy-efficient edge computing engines*
- *Explore unique features of emerging devices for the development of disruptive computing accelerators/engines*
- *Valorise the innovations and technical products through start-ups/ spin-offs*



The Quantum Computer Stack

> 'We develop, design and demonstrate different flavours of low-power computing engines to enable a wide range of edge applications'

Research challenges

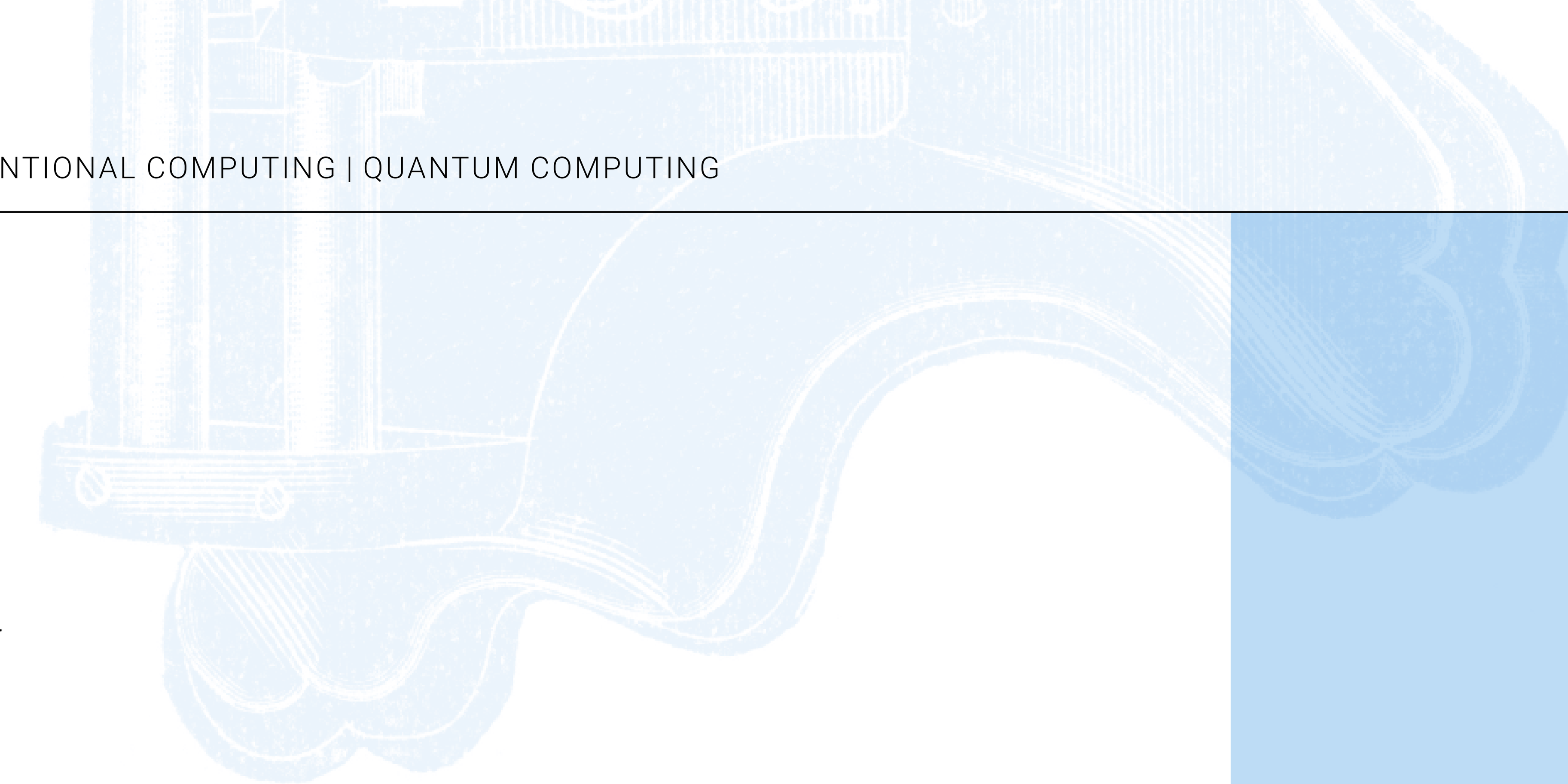
Quantum computing and Quantum sensing

Realising the promise of a quantum computer requires the development of different layers of hardware and software, together referred to as the quantum computing stack. At the bottom of such a stack, the quantum-hardware layer comprises the physical implementation of the qubits. Moving to higher layers in the stack, those qubits are controlled and read out by a classical electronic interface, which is in turn connected to the quantum-computer architecture layer. That layer controls the algorithm flow and translates a high-level quantum algorithm into hardware-specific electrical signals. Used in combination with classical electronic control, quantum devices can be used to build sensors whose performance exceeds their classical counterparts, such as extremely sensitive magnetometers. At EEMCS, we develop the technologies needed to realise different layers of the stack and we build prototypes to validate their performance. We strive to integrate the different layers into larger systems, e.g. by combining qubits with cryogenic control electronics or by controlling the algorithm execution on physical qubits via an integrated microarchitecture. We specifically focus on:

- Fabrication of quantum devices at industrial scale and quality
- Integration of quantum and classical devices in scalable platforms
- Development of an integrated (cryogenic) electronic interface
- Hardware and software architectures
- Integration of quantum accelerators within classical computing machines

Edge computing

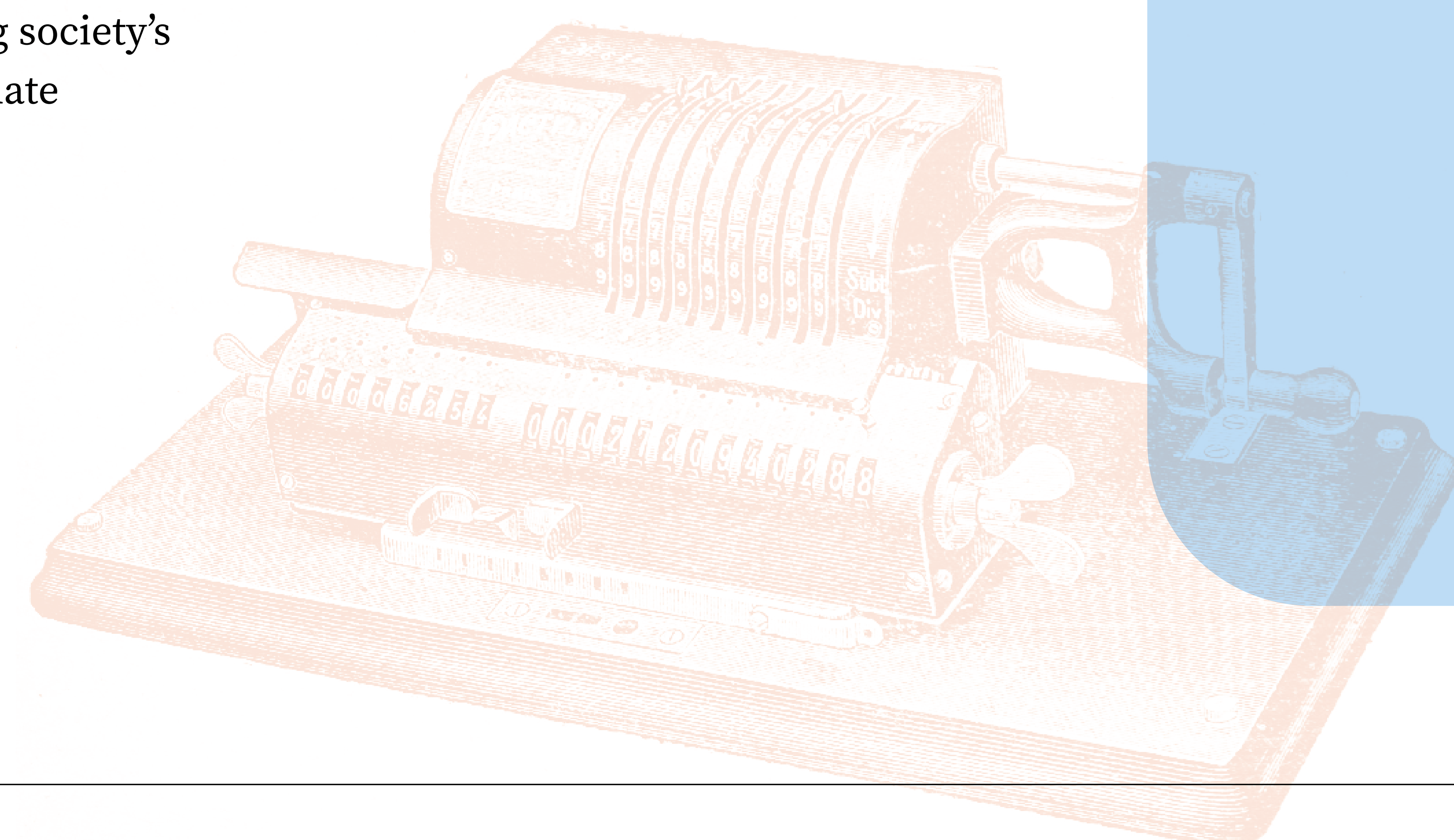
We develop, design and demonstrate different flavours of low-power computing engines to enable a wide range of edge applications, including AI driven ones. A holistic approach is used to realise 100x or better energy efficiency. It covers a coherent full stack (e.g. device, circuits, micro-architecture, etc), identifying opportunities to make discrete capability steps at each level. For instance, at the microarchitecture level, local/in-memory computing is used to avoid energy-costly data transports. In addition, a wide range of emerging non-volatile devices, such as memristors and spintronics, are investigated. These not only reduce energy consumption (because they not leak), but also enable event-driven based computing such as neuromorphic computing based on spiking neural networks, inspired by biological principles.



Impact on society

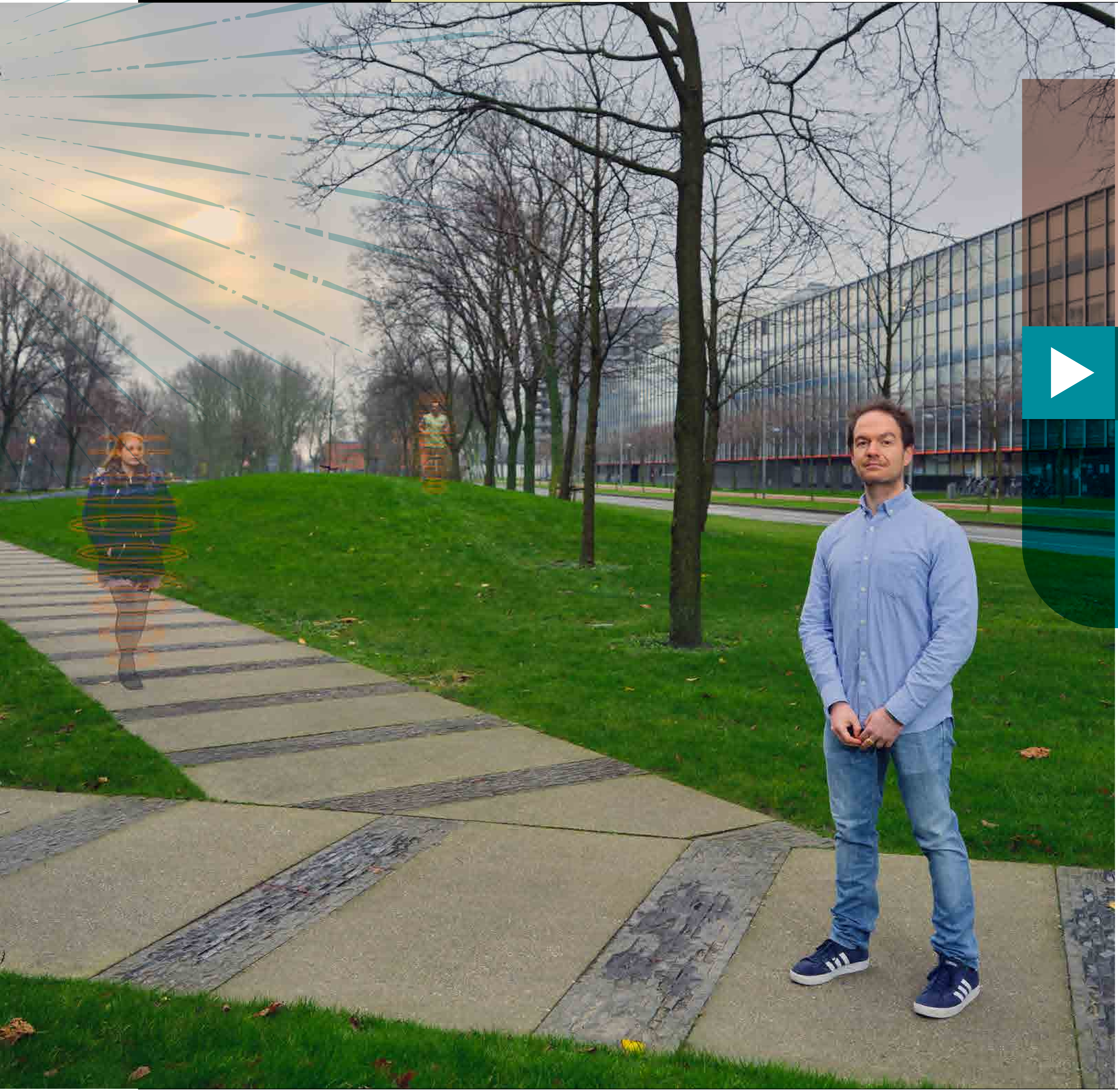
- Enabling optimal solutions of complex problems that conventional computers can't handle. There are many current applications whose solutions would require thousands of years using traditional computers, and these could be achieved in days if not hours by quantum computers. Examples are drug design & development, financial modelling, logistic optimisation and weather forecasting.
- Enabling cost-effective computation solutions for currently infeasible AI edge applications. Ultra-low-power computing engines are the basis for many applications across areas such as personalised healthcare, smart homes, drones, environmental monitoring and smart agriculture. These include edge computing, edge analytics, edge intelligence and edge real-time decision making.
- Contributing to a greener world and climate change prevention, bringing new greener digital solutions to the market. We target solutions reducing energy use by at least 100x per operation, thereby increasing society's resilience and preparedness to tackle the climate challenge. ■

> 'We target solutions reducing energy use by at least 100x per operation'



Innovation approach

- **Strategic collaborations**
  - Semiconductor industry
  - Computer infrastructure manufacturers
  - Information technology and software sector
- **Convergence**
  - Use edge devices for better understanding of our health, e.g. the brain
  - Combine AI and edge devices for real-time early-stage detection of diseases through implantable and wearable devices
- **Research infrastructure**
  - Kavli Nanolab at the Van Leeuwenhoek Laboratory
  - Else Kooi Lab
- **Research topics**
  - Quantum computing architectures
  - Quantum-classical integration,
  - Cryo-CMOS circuits/systems
  - Quantum sensing
  - Neuromorphic computing
  - Computation-in-memory,
  - Spin-ware computing
  - Approximate computing
  - Hardware architectures for edge AI
  - Hardware architectures for machine learning and big data



Communication & sensing

The human desire for 'smart environments' and to be 'connected anywhere, anytime' is changing the way we interact with our surroundings, and will drastically impact our society. Wireless data traffic is growing exponentially, driving mobile networks and their devices from 4G to 5G and 6G services, able to handle more users and services at higher data rates and lower latency. Using larger signal bandwidths and multiple receivers/transmitters will therefore be mandatory.

At the same time, the Internet-of-Things (r)evolution will require connectivity of large numbers of devices at low data rates – all with rigorous requirements around response times and energy usage. Spectrum scarcity will demand dynamic spectrum usage based on cooperative spectrum sensing and cognitive radio concepts. Moreover, GPS-free, reliable and accurate location estimation will be essential. Other aspects expected to play a crucial role include the enhancement of societal safety and security (including environmental monitoring and autonomous transportation), microwave and THz sensing systems.

AMBITIONS

- *Energy-efficient wireless systems*
- *Flexible, high-speed and low latency communication links*
- *High resolution radar and localisation systems*
- *Cognitive sensing systems*
- *Sharing electromagnetic spectrum in communications and sensing*
- *Digitalisation and integration of the RF frontend*
- *Broadband low loss (sub) mm-wave/ THz wireless technologies*
- *System form factor and cost reduction*

> Teaming up with the industry and aiming for digitalisation will yield novel leading car radar solutions with their functional blocks, antennas, and signal processing

Research challenges

Research within this theme focuses on developing disruptive technologies for future connectivity; and sensing solutions that provide higher performance, accuracy and functionality at reduced energy usage and costs.

Massive Multiple-Input-Multiple-Output (mMIMO)/ phased-array antenna systems

Wireless systems using directed transmission and reception (beamforming) are considered the way forward to handle exponential growth in data traffic. Advanced beamforming techniques are also crucial to radar and localisation systems, which will be able to establish wireless links and detection at a fraction of the energy needed by older wireless generations. However, beamforming relies on massive Multiple-Input-Multiple-Output (mMIMO)/phased array antennas, which need many RF frontends. This, in turn, requires a significant increase in hardware complexity (e.g., 64x), signal processing, power consumption, and costs. As a result, there is a growing need for low-cost, highly integrated energy-efficient transmitter/receiver (TX/RX) RF frontends. Unfortunately, today's wireless equipment almost exclusively uses analogue circuits implemented in multiple semiconductor technologies, leading to poor system integration and severe linearity/efficiency design trade-offs. Even in low traffic situations, standby power consumption in conventional systems also remains high: a major concern in terms of operational costs and CO_2 footprint.

Digital intensive wireless / radar solutions

For commercial sub-6GHz wireless bands, digitally assisted or fully digital-TX (DTX) RF frontends can in principle provide many benefits. These include lower standby power, improved integration, and higher functionality/(re)configurability (e.g. changing operating frequency or modulation schemes without changing the core hardware). This offers improvements to design logistics and costs. Still missing, however, are the DTX-compatible technologies and the design techniques needed to meet stringent performance requirements. The ME department aims to change this situation and develop jointly with industry tomorrow's digital radar and communication solutions.

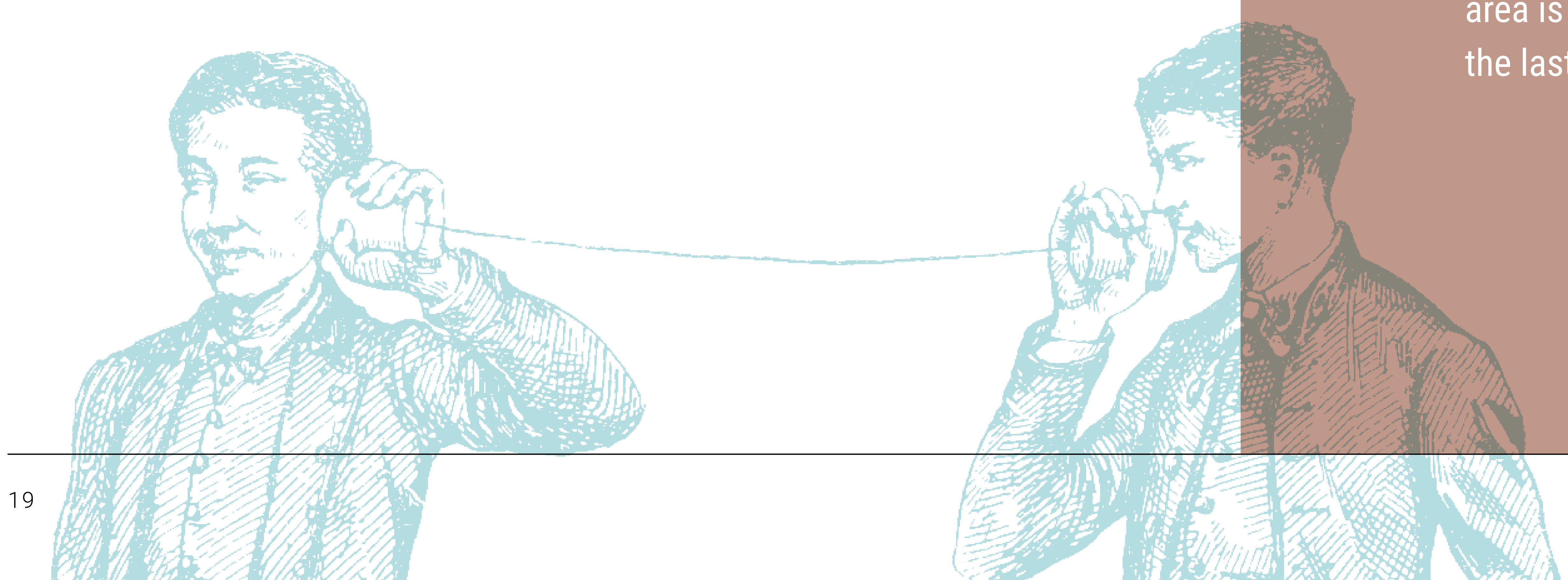
Submm-wave backhaul / car radar solutions

Sub-mm-wave/THz frequencies and quasi-optics techniques are envisioned to implement a wireless network's high-speed, point-to-point, backhaul connections. Using small wavelengths in combination with dielectric lens-based antennas can provide highly directed beams (at small antenna form factors). These require almost no TX power to establish a wireless link. Car radars are typically short-range and benefit enormously from using very high frequency/short wavelengths, improving their resolution and form factor. Teaming up with the industry and aiming for digitalisation will yield novel leading car radar solutions with their functional blocks, antennas, and signal processing.

Cognitive radar
Building situation awareness in modern radar applications requires smart combination of sensing waveform agility with multi-aspect observation of the scene and mission-adaptive signal processing. Switch from a single-node to multiple-nodes radar solutions presents one of paradigm shifts in modern radar. Combination of Bayesian learning approaches with data driven AI-based approaches offers flexible and robust signal processing solutions for classification and tracking of radar targets. Increased degrees of freedom in digital waveform generation, beamforming, distributed sensing and multi-thread signal processing raise the need of advance radar management solutions, which will close the cognitive loops within the radar sensing process and satisfy challenging societal needs on a broad spectrum of sensing solutions from human activities recognition and vital sign extraction till autonomous vehicle operation.

Impact on society

Providing solutions for high-performance, wireless sensing systems that sustainably and cost-effectively enable the 'smart society of the future'. ■



Innovation approach

- **Focus on strategic collaborations that span multiple disciplines, e.g. from RF power devices, SOC development, and complete system integration**
  - With the communication technology sector on sub-6GHz base stations for wireless networks
  - With semiconductor companies on (car) radar
  - With the communication technology sector on backhaul connections
  - European and National research grants

- **Convergence**
  - By bringing the digitalisation of the RF frontend closer to the antenna, it becomes possible to merge traditionally separate domains, such as signal processing, digital design and RF circuits, and to introduce all-encompassing solutions for the first time. This opens new opportunities in system integration, performance, functionality and cost reduction. A world-leading role for ME in this area is in reach using the foundation established in the last decade

- **Research Infrastructure**
  - The various XG labs will be concentrated on the 21st floor.
    - *Sub-mm-wave lab*
    - *RF power lab*
    - *SOC testing lab*
  - The radar labs will be concentrated on the 22nd and 23rd floors.
    - *DUCAT*
    - *PARSAX*
    - *MESEWI*
    - *Mm-wave radar lab*

- **Research topics**
  - RF/sub-mm-wave frontends
  - Digital transmitters
  - Reconfigurable transceivers
  - Car radar units
  - Waveform-agile radars
  - Sparse and non-regular antenna arrays
  - Phased array radar management
  - Radar targets, clutter and interference classification
  - mMIMO/phased array
  - WiFi
  - RF/sub-mm-wave signal generation and detection
  - Quasi-optical antennae and lenses

Artificial intelligence

The digital transformation is irreversible and rapid and has changed much over the past decade. Artificial intelligence (AI) plays a key role in digitisation, with almost endless applications. It is expected to make a massive socio-economic impact, relating to many of the challenges we are facing. Responsible and capable AI is set to affect almost every aspect of daily life, and the high-level and applied AI research we are undertaking will help to ensure that benefits are maximised.

AMBITIONS

AI, Data & Digitalisation have had a growing, university-wide influence for several years – across all areas of research and all educational programmes. At TU Delft, we believe that the continued and successful application of an Artificial Intelligence (AI)-driven approach demands a convergence between AI research (foundational and applied) and advancing the sphere of AI: the way in which a specific field of research becomes state-of-the-art.

- *To conduct high-level AI research, ranging from foundational to applied, in a multi-disciplinary team (TU Delft AI Labs). Our fundamental AI research aims to discover novel basic principles for AI, design novel AI algorithms, and develop novel theories to analyse those AI algorithms. Applied AI research concerns the development of innovative AI-enabled systems that address challenging scientific and societal problems.*
- *To educate new generations of AI scientists and AI engineers, teaching students AI at a high and internationally recognised level.*
- *Long-term collaboration with industrial, societal, and academic partners, exploring real-life applications of AI arising in science, society and technology.*

Research challenges

- Becoming leaders, both nationally and internationally, in the fields of AI science and engineering.
- Creating a diverse, safe and strong AI community that catalyses scientific collaboration and discovery.

Responsible design and engineering of human-centred AI and data driven Systems

AI, data and digitalisation are increasingly essential when solving important scientific and societal issues. At EEMCS, we want AI and data driven systems to make human activities more efficient and sustainable, but we also want these systems to be designed to make human activities fairer, more democratic and more likely to lead to human wellbeing. As a university of technology, we combine a focus on human-centricity with a focus on responsible design and engineering – bringing humans and engineering together to empower people.

Machine learning

Our world is become ever-more data-driven. The data we collect has the potential to improve decision making across all aspects of society, from disease treatment through to improvements in logistical processes or traffic flows. With existing machine learning techniques, it's important to make an impact on real-world systems, such as improvements to data access, use, quality, labelling, sensitivity, security and prediction. EEMCS is contributing towards making machine learning techniques more effective and easier to use, so they have a positive impact on everyone's quality of life.

AI for energy and sustainability

The energy transition exposes the complexity of our energy network. For a sustainable future, the system must be both 'green' and balanced. For example, if wind production at a certain moment increases, you must reduce energy production at another source. The current energy system is not yet ready to deal with a large and varied amount of renewable energy sources.

> 'EEMCS is contributing towards making machine learning techniques more effective and easier to use'

AI for health and wellbeing

AI is expected to play a role in addressing the world's urgent healthcare challenges, such as shortage of healthcare workers; increasing health disparities; emerging threats from global pandemics; the management of non-communicable diseases (e.g. cancer) and age-related diseases (e.g. Alzheimer's disease); and the long trajectory for development of new drugs. At Delft, we believe that AI can enable innovative approaches to health, wellbeing and healthcare, and shape the future of medical professionals, patients and their families.

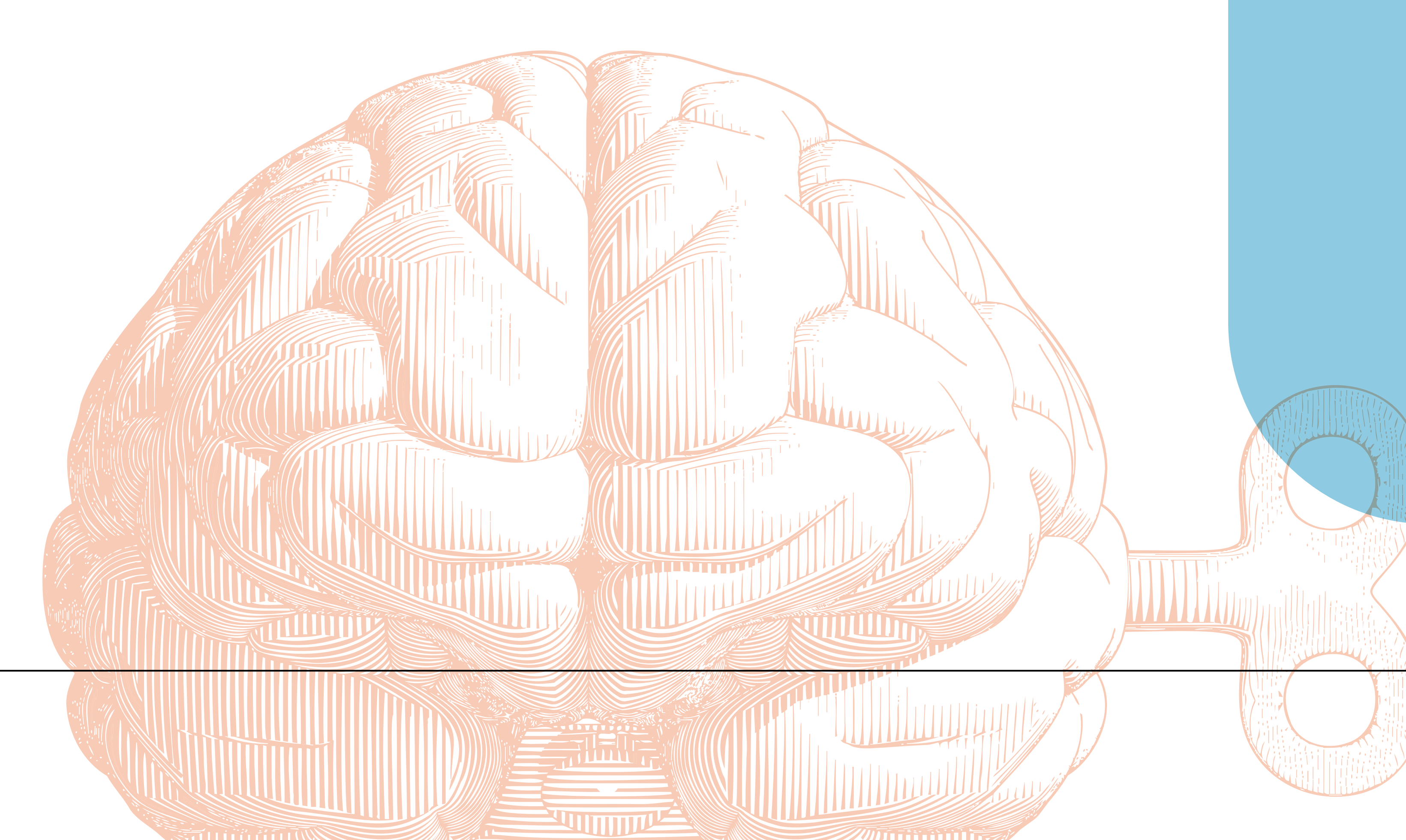
AI for port and maritime
With increasing digitalisation, the port and maritime sector is undergoing rapid changes. AI will play an important role in this development. Concrete applications include the optimisation of logistic, production and other planning processes; enabling (semi-)autonomous transport over water and land; and turning the port into a system where many parties interact. To make ports future-proof, we need to search for answers to unanswered questions in AI, and translate the latest insights into the port and maritime domain.

AI for Peace, Justice and Security (PJS)
Making AI fair, just and beneficial for all of society, while also keeping the Dutch industry as a competitive world player in this segment of technology. This enormous challenge brings many opportunities to domains related to Peace, Justice and Security (PJS). AI is changing the public domain, because actions, communications and associated public/private services are becoming increasingly automated, programmable and intelligent. The use of AI within PJS must strike a proper balance between new and optimised functionalities, while also protecting from AI vulnerabilities and dependencies both impacted citizens and the institutional foundations of our society.

AI for technological industry
Following the industrial revolution, a new revolution is taking place in the technology industry itself with rapid developments in AI. In many companies, AI already plays an important role in business operations, for example in optimising maintenance processes, energy use and product development. To stay ahead internationally, we need to translate the newest AI insights into the technology industry and look at the opportunities for existing AI technologies in new applications. In-depth knowledge of AI provides technology industry professionals with important tools. Think, for example, of smart algorithms that improve human-machine interactions so that they can work together in a business process, doing exactly what they do best. Or physics-aware AI, a promising new technology that allows machines to understand the laws of nature just as humans do, and to work much more efficiently and accurately. Testing such solutions is often very laborious and costly in practice, and so we develop highly detailed simulation models and digital twins that can take care of part of the practical testing.

Impact on society

AI has the potential to have a massive impact on many industries and numerous aspects of society such as autonomous driving, UAVs, satellites, patient-centred healthcare services, forecasting of extreme weather events, optimisation of energy generation and consumption and technology-enabled agriculture.



Innovation approach

- **Strategic collaborations**
  - ICAI labs
  - Delft AI labs
  - Societal institutions
  - Silicon valley
  - NWO LTP ROBUST on Trustworthy AI
  - NWO LTP Plant-XR
  - Knowledge Centres - KNMI | Deltares
- **Convergence**
  At a regional level, TU Delft collaborates with Erasmus MC and Erasmus University on AI for healthcare, such as AI for sustainable Intensive Care Units (ICU) and AI for personalised cancer treatment
- **Research topics**
  - Beyond deep learning: symbolic modular neural networks
  - Probabilistic reasoning in deep neural networks
  - Physics-informed machine learning for weather and climate modelling
  - AI-enabled health care services in the cloud
  - AI technologies for the operating room
  - AI-driven perception in autonomous vehicles and advanced driver assistance systems (ADAS)
  - Distributed learning in multi-agent systems
  - Relative Positioning, Navigation and Timing (PNT) of swarms

Students and education

The EEMCS faculty educates engineers in the disciplines of electrical engineering, applied mathematics and computer science. We envision an inclusive education environment which helps a diverse student population to develop into creative engineers of the future. We want to ensure that students experience a positive and supportive atmosphere, and all students who match with our education programmes are welcomed and accepted, irrespective of gender, background, disability or religious beliefs. The EEMCS education environment is a place where scientifically curious students can develop into adaptive and responsible engineers with a sound technological foundation – able to reflect on social context and to tackle global challenges in both local and international contexts.

Our education portfolio

EEMCS is active in a broad educational landscape. Our education programmes cover the fundamental disciplines in electrical engineering, mathematics and computer science and offer exploration of interdisciplinary fields such as embedded systems, artificial intelligence, sustainable energy technologies, biomedical engineering and technical medicine. We are known for our excellent and innovative teaching, and we contribute significantly to the development of all TU Delft engineers by offering fundamental skills such as mathematics and digital skills from a pre-university level.

Bachelors

Our bachelor programmes give students a good disciplinary foundation in electrical engineering, applied mathematics or computer science. We are continuously working on a socially safe and supportive education environment, offering a mentorship programme and academic support to all students. We believe strongly in the TU Delft vision to train ‘T-shaped’ engineers in the bachelor. To ensure this, the faculty contributes a range of thematic minors in computational science, finance, computer science, AI, electrical engineering and sustainable energy systems. This allows our own bachelor students and students in other disciplines to expand their horizons. Our bachelor graduates can pursue masters’ studies in either the same domain, adjacent technical domains, or complementary non-technical domains (for example science education).

Masters

Our master programmes reflect the research expertise of the faculty, allowing students to pursue research projects in either the same domain, adjacent technical domains or on interdisciplinary topics. We contribute significantly to interdisciplinary masters’ programmes and continue to expand our education portfolio to deliver engineers of the future in emerging areas, such as quantum information science and data science and AI technology. Students follow small-scale research projects for their master thesis. We provide a socially safe and supportive environment including a daily supervision by our academic staff and researchers. Our connection with research institutes and other industries ensures that our students can follow internships of academic standard as they also have the opportunity to venture beyond the academic work field.

AMBITIONS

- *The composition of our student population is representative of society*
- *Our education environment is inspiring, safe and supportive for all students who match our programmes*
- *Students develop into adaptive, responsible engineers with a sound technological foundation*
- *Students are facilitated to engage with their passion, individual gifts and desires within their field of expertise to widen their own horizon*
- *Through our educational environment equal chances of success and personal development for every student are established*
- *Our study programmes provide students with relevant knowledge to successfully tackle with societal needs in engineering*
- *More students successfully complete our study programmes to fulfil the societal need for engineers*
- *Our team teaching approach ensures that education remains personal*
- *Our lecturers continuously improve and use evidence based innovation to maintain high quality education.*

Doctoral education / Graduate school
The third-cycle of higher-education includes courses spread over three themes (disciplinary, research skills and transferable skills), with research and the writing of a doctoral thesis undertaken in close cooperation with a supervisor. The courses for doctoral education are offered by the Graduate School, University Research Schools, Summer Schools and guided training. They also involve contributions by our PhD students at international venues such as workshops, conferences and scientific journals.

> 'To guarantee the quality of our education and adapt quickly to changing circumstances, innovation in education at EEMCS is constant, on an evidence-informed basis'

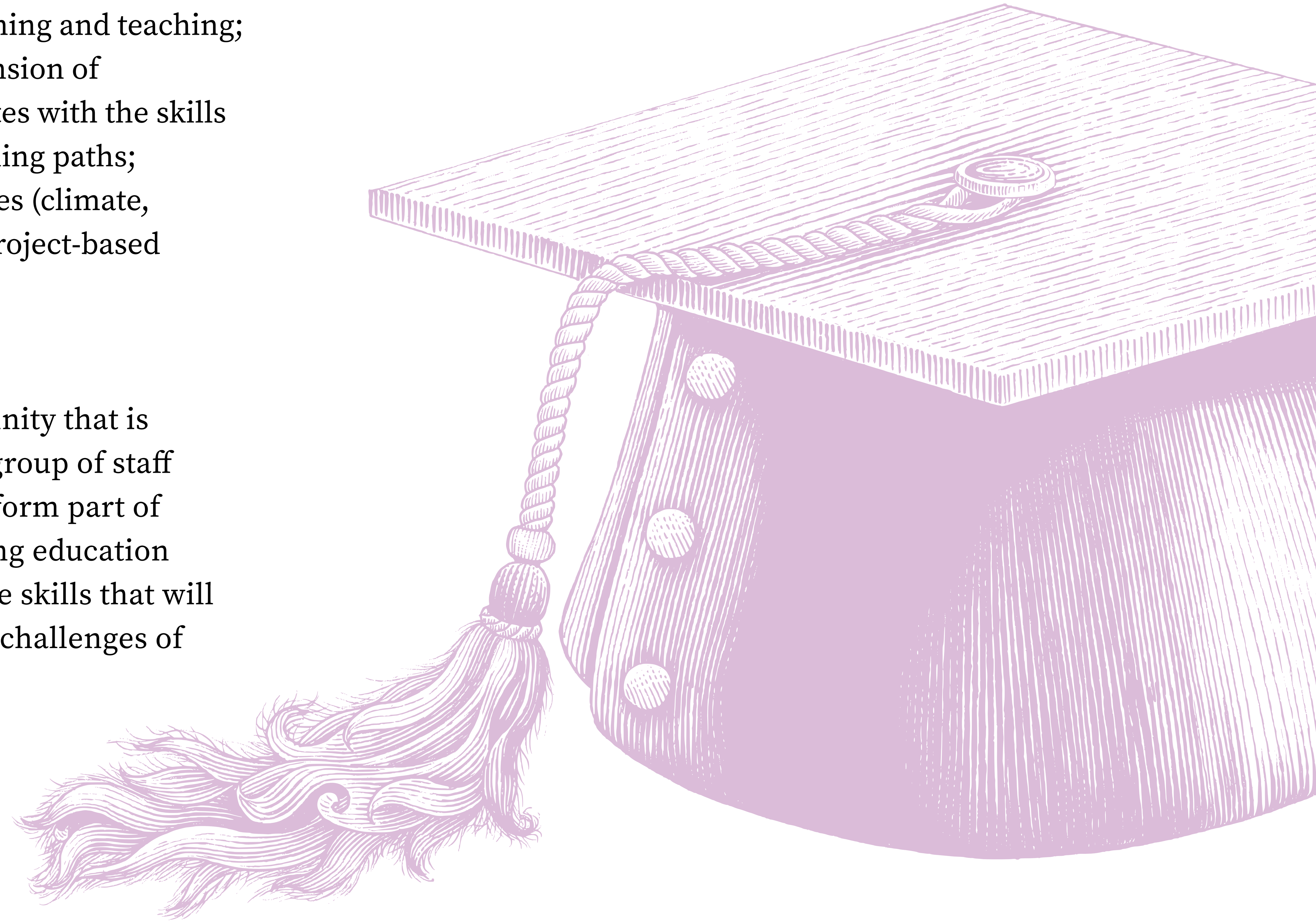
Lifelong learning
EEMCS has a strong footprint in the online portfolio of the Extension school. We have a focus on the portfolio's Energy and AI categories and contribute significantly to Skills for Engineers.

Our education programmes
- cover fundamental topics as well as state-of-the-art examples and applications from the study domain;
- integrate technical disciplines with interdisciplinary, inter- and intrapersonal skills;
- incorporate education methods and the learning environment, adapting to the needs of new generations of students in achieving excellent learning and teaching;
- contribute to innovation and the expansion of knowledge, and equipping our graduates with the skills to continue personalised lifelong learning paths;
- reflect socially relevant research themes (climate, energy, health and digital society) in project-based education to offer context.

Our education community
We strive to create an education community that is welcoming and supportive of a diverse group of staff and future engineers. Everyone should form part of our inspiring, challenging and motivating education environment where students develop the skills that will enable them to tackle the technological challenges of the future.

Our staff is committed to high quality education and seeks continuous professional development. Our lecturers are UTQ trained in order to keep their knowledge and skills up to date. They translate the mission of the faculty into challenging, activating and motivating education and are recognised and rewarded equally for research as well as education.

Our students are encouraged to work in interdisciplinary teams. The goal is to not only train them to become experts in their field but to also equip them with a deeper understanding of the social and ethical responsibility of engineers.



Innovation approach

Innovation in education at EEMCS is constant and needs to adapt quickly to changing circumstances in order to guarantee the quality of our education. As a result, we offer world-class programmes where students successfully develop their knowledge, skills and personalities. Our teaching philosophy is modelled on the concepts of project-based and blended learning. In transitioning from small-scale programmes to larger scale programmes, the faculty actively searches for innovations enabling small-scale experiences in a larger scale environment.

Our study programmes continue to address important global challenges, in order to remain relevant and appeal to a broader potential student population.

Safeguarding the wellbeing of staff and students is at the core of our innovation approach. We believe in creating an education environment where staff and students can flourish, where there is a balance between work-pressure and success and where there is room for education innovation. Maintaining education quality is essential, and based on the following:

Education Efficiency
- we implement blended team teaching to increase the students' performance and make education more scalable (e.g. PRIME, WebLab, Queue, Project Forum, etc).
- we foster a culture of innovation in our teaching – for instance through the Delft Education Fellowship, an initiative from the TU Delft Teaching Academy and sharingfaculty based best practices.

Education effectiveness
- we (re)design education to fit with students' ambitions and talents, considering societal and scientific relevance, e.g. sustainability and responsible engineering.
- We employi teaching approaches that suit students with special needs
- we actively support teaching staff to achieve all ambitions.

Engagement
- we employ proactive teaching teams including teaching assistants and student mentors who students can relate to, creating a feeling of belonging that motivates and engages students.

Inclusivity by design
We design new curricula with the focus on creating an inclusive education environment where students can develop into adaptive and responsible engineers.

Open education
- we collaborate with other leading experts and create open educational resources to improve education quality.

Collaboration
- we foster a collaborative approach between support staff, teaching teams and lecturers to preserve (and further distribute) acquired knowledge. ■

PRIME

The PRogramme of Innovation in Mathematics Education (PRIME) is a team effort that is all about redesigning mathematics courses for engineers. As such it is part of the Interfaculty Teaching from the department of Applied Mathematics (DIAM) at TU Delft. PRIME delivers open educational resources that are also shared with other institutions.

The aim of this innovation is to redesign the current math courses for non-math students to a blended learning cycle design intended to:

- *Improve study results*
- *Improve connection between mathematics and engineering*
- *Increase students active participation and motivation*

Courses are designed following the PRIME-cycle: prepare, participate, practice

The PRIME-cycle

PRIME on tudelft.nl

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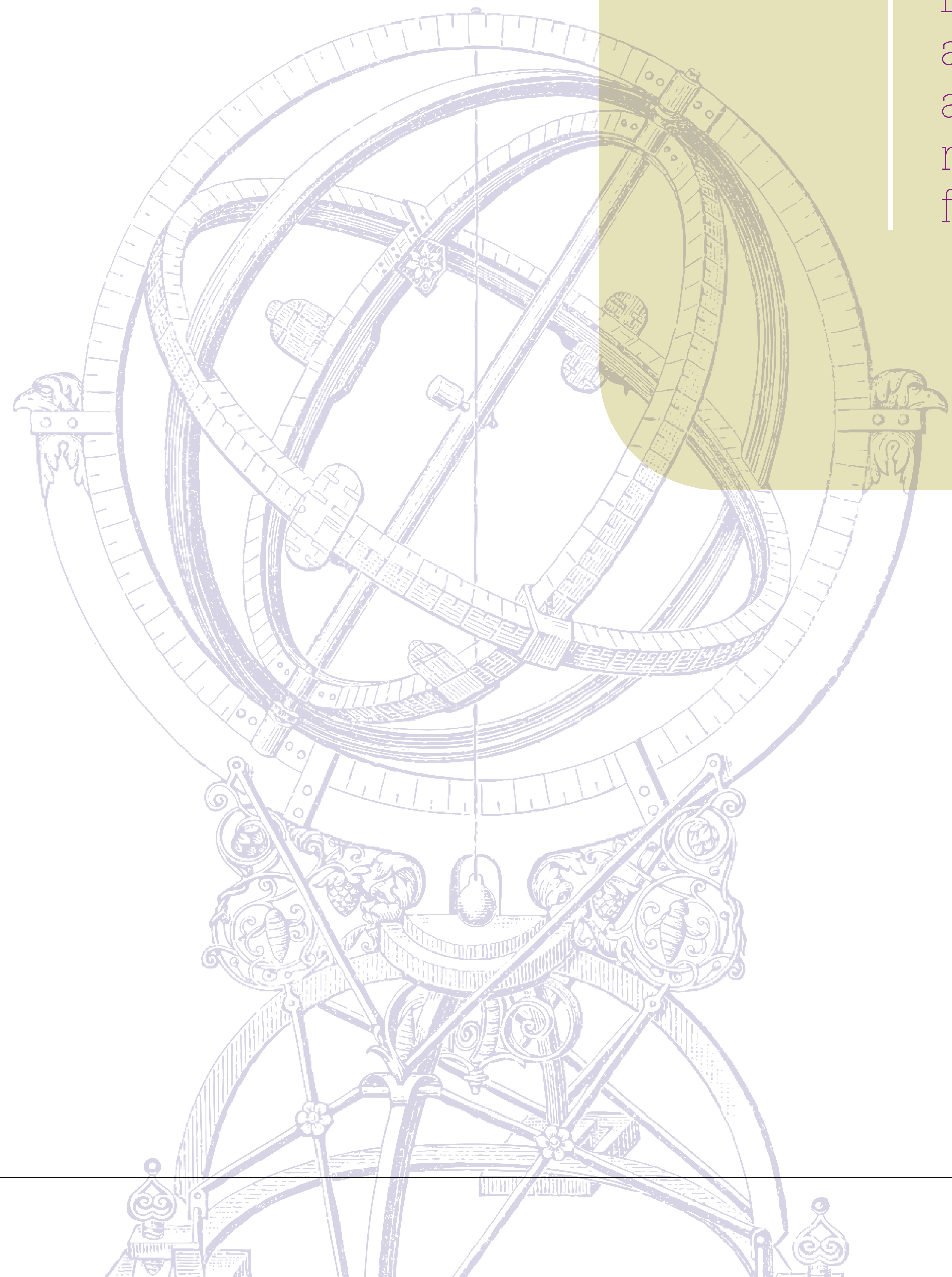
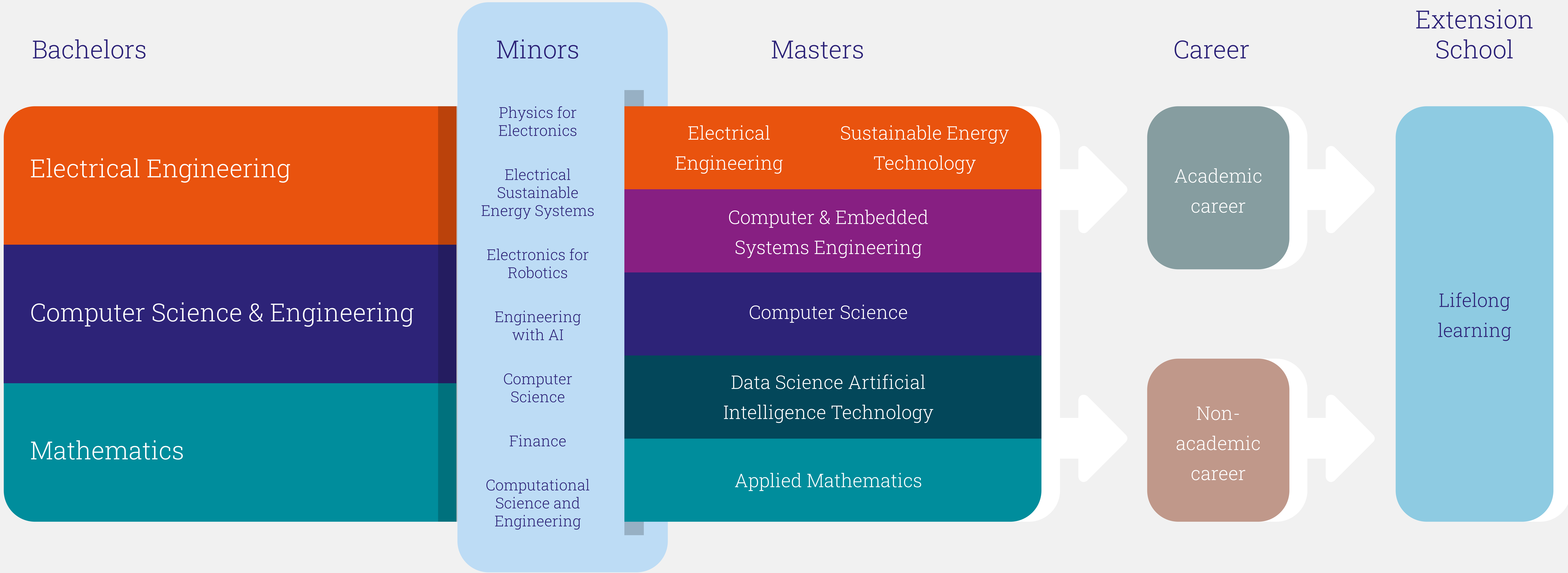


Education programmes

Overview of our current programmes



People and community

People are central to achieving our ambitions in both research and education as well as innovation and impact. Employing highly talented people, educating students to become creative engineers of the future, and engaging and collaborating with others are therefore essential. At EEMCS we actively work on creating an environment that is diverse, challenging, supportive, safe and inclusive. Professional and leadership development are stimulated and facilitated to help talents grow. It is a learning and working environment where people are encouraged to be the best versions of themselves, and have room to fulfil their own ambitions and contribute in solving major societal challenges.

Community

Being part of a community gives sense of belonging and identity and supports growth and empowerment. Community building at large is encouraged within EEMCS. People and community refers to our students, PhDs, postdocs, academic staff, lecturers, support staff, leadership, alumni and others we work with.

Communities within our faculty come in many forms and in various ways. By working in project research teams, being a member of the faculty student council or works council, participation in diversity & inclusion initiatives, being part of a network, department or a team. The result is a vibrant, inclusive and ever evolving environment where people can connect and collaborate.

Values, diversity and inclusion

At EEMCS, we firmly believe that diversity in perspectives and talents drives excellence and leads to better results. An inclusive organisation makes the best possible use of diverse qualities and competences. Differences are valued and even sought to be explored.

In an inclusive learning and working environment all people are respected and can be themselves regardless of their gender, age, sexual orientation, religion, cultural background, life stage, function limitation or educational level.

Guiding principle is that everyone is responsible to create and maintain a safe and inclusive learning and working environment. Behaviour and interactions are guided by our 'DIRECT' core values (diversity, integrity, respect, engagement, courage and trust).

EEMCS embraces diversity and inclusion by:
- Stimulating a culture where people can be themselves and are considerate of others.
- Respecting and valuing alternative perspectives.
- Fostering open and inclusive communication.
- Improving the gender balance of student population and academic staff.
- Building strong teams that are diverse in composition.
- Transparent and visible monitoring of diversity.

> 'At EEMCS, we firmly believe that diversity in perspectives and talents drives excellence and leads to better results'

Attraction & retention of top talent

To achieve our ambitions, people are key and our most important asset. Sufficient high-quality staff, both in terms of expertise and competences are needed. Staff members are crucial for ground-breaking research, transferring knowledge to students and securing the necessary 2nd/3rd flow funding.

Our abilities to attract and retain talented and engaged employees are strategic priorities. We focus on being more visible, active talent attraction and talent development. For academic staff there is room for variation in career paths linked to the various ambitions on research, education and innovation and impact.

EEMCS is visible to the outside world by:
- Profiling in themes, technologies, start-up possibilities and teams.
- Transparency in career paths for academic staff.
- Development opportunities for professionals in support positions.
- Talent and leadership development.
- Diverse and inclusive environment.
- Importance to health and wellbeing.

EEMCS recruits talent by:
- Active talent attraction, using networks and searching.
- Transparency in recruitment procedures.
- Fair and unbiased selection processes.
- Valuing performance, soft skills and (leadership) potential.
- Diversity in composition of staff and teams.

EEMCS is committed to retain and develop talent by:

- Offering a good start with a structured onboarding and embedding.
- Setting clear goals and having regular dialogues on future development.
- Supporting development by feedback, training and giving (organisational) responsibilities
- Accelerating careers by quickly recognising and appreciating potential and results.
- Recognising and valuing individual achievements as well as contributions to others' achievements.

> 'Leadership is pivotal and leaders are never done learning'

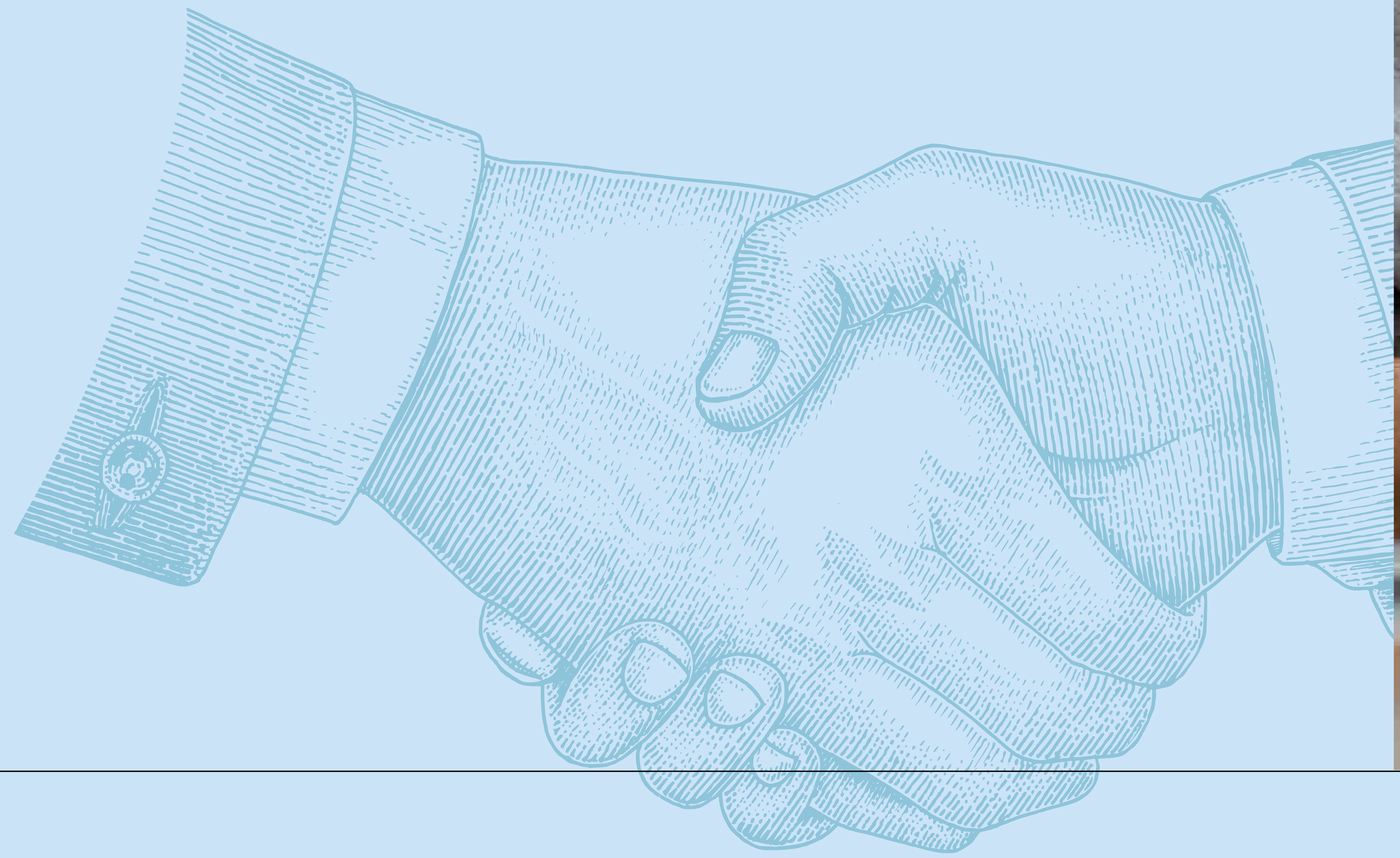
Leadership

Leadership from each and every one of us is crucial in realising our ambitions, whether it is about research and education, talent development or creating an open and inclusive environment. EEMCS' view on leadership is built on the pillars of ownership and collaboration, vision and strategy, self-awareness and situational awareness, trust and integrity, initiative and courage and attracting and encouraging talent.

It always starts with personal leadership, knowing who you are and making conscious choices in how you want to fulfil your role. When it involves leading others, an organisation or having impact in academia, leadership is also knowing what kind of leader you are or would like to be. Leadership is pivotal and leaders are never done learning.

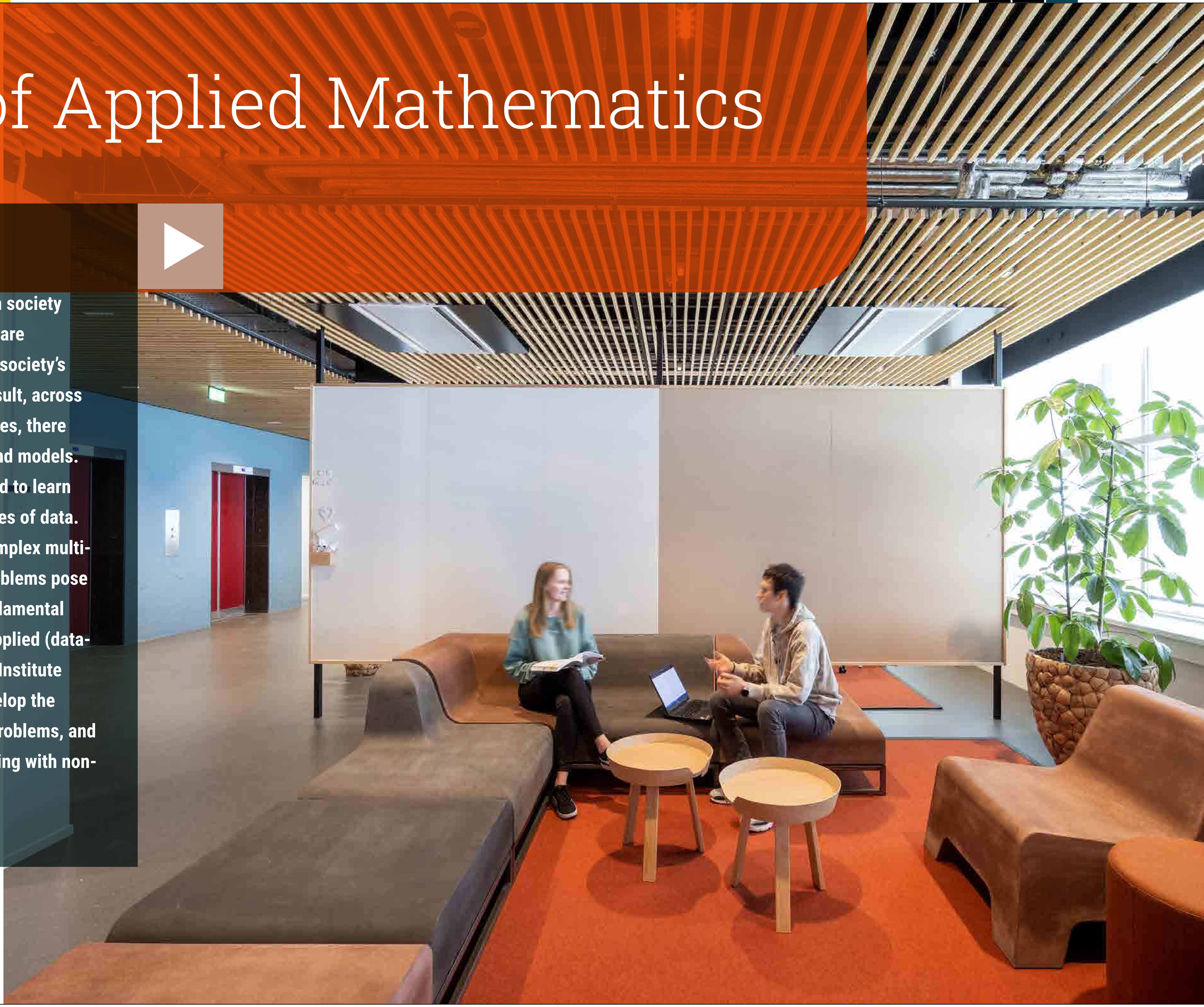
EEMCS conveys this message by:

- Encouraging leadership dialogues and culture of reflection and feedback.
- Supporting continuous development of (personal) leadership for all functions and all levels.
- Providing ample leadership and management development opportunities, programmes and training. ■



Delft Institute of Applied Mathematics

Mathematics plays a fundamental role in the development of science, technology – and in society at large. Fundamental and applied problems are becoming more and more interwoven as our society's technological complexity increases. As a result, across many of our society's technological challenges, there is an urgent need for mathematical theory and models. For example, many scientific disciplines need to learn properly from increasingly available quantities of data. Data modelling is required to understand complex multi-scale processes in climate change. Such problems pose mathematical challenges from the most fundamental (analysis, probability theory) to the highly applied (data-driven models, numerical algorithms). Delft Institute of Applied Mathematics (DIAM) aims to develop the mathematical theory needed to solve such problems, and to disseminate this knowledge by collaborating with non-mathematicians.



KEY AMBITIONS

DIAM makes essential contributions at the forefront of mathematical research, creating and studying mathematical models and disseminating knowledge to empower current and future technological innovations. The strategy that enables this – our Mission – consists of three clearly defined statements, roughly related to research, education and valorisation:

Mission 1
DIAM conducts high-level mathematical research ranging from fundamental to applied, and bridges gaps in between. Fundamental research aims to understand structures at a deep level. Applied research concerns the development of new mathematical models and tools that can be transferred to (and applied by) the mathematical and scientific community, as well as by partners in industry.

Mission 2
DIAM educates new generations of mathematicians, scientists and engineers, teaching students mathematics at a high and internationally recognised level.

Mission 3
DIAM collaborates with industrial, societal and academic engineering partners to deepen the understanding of complex systems arising in science, society and technology.

We follow a long-term strategy that strongly emphasises the importance of our human resources. In order to achieve our mission, an even greater emphasis will be placed in future on retaining our academic staff by offering clear career perspectives.

Focus areas

Inspired by the Sector Plan process, our research is structured in five focal areas:

1. Partial differential equations
2. Mathematics of data science
3. Computational mathematics
4. Mathematics of discrete structures
5. Stochastic modelling in science and engineering

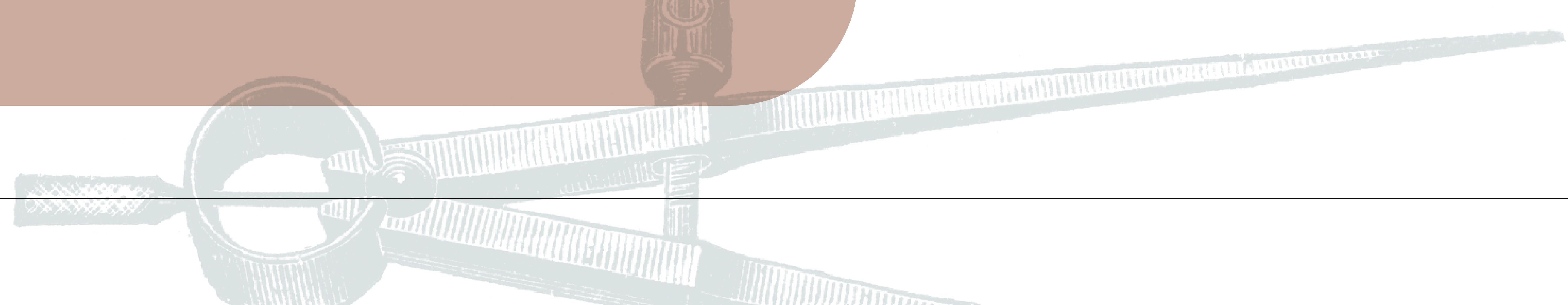
Alongside the focus areas are two important research themes. These themes relate to more specific fields of application than the more general focal areas, namely Financial Mathematics and Mathematics of Quantum Technology.

Research challenges

- Becoming a leader, both nationally and internationally, in the fields of partial differential equations and the mathematics of data science.
- Strengthening the coherence, safety and diversity of the DIAM community, and improving the scientific climate.
- Hiring the right people, making them feel at home within the department and providing an all-important perspective on professional growth. We also seek to ensure a safe and fruitful (academic) environment, along with excellent support in achieving personal goals.

Impact on society

There are ample opportunities to disseminate newly developed mathematical knowledge across societally relevant fields of application, and also many opportunities to be inspired by scientific and engineering challenges that lead to new research questions in mathematics. DIAM works on topics ranging from forecasting volcanic ash clouds, to developing simple inexpensive MRI scanners, to planning emergency medical services. We are also involved in the research themes Safety and Security, Energy Transition (also connected to Climate) and Health & Wellbeing. Regarding educational innovation, DIAM is deeply involved in the Programme for Innovation of Mathematics Education (PRIME).



Innovation

- **Strategic collaborations**
  DIAM already maintains strong connections with industry, and we aim to form yet more strategic connections both with societal and industrial stakeholders and with the academic world (both mathematical and engineering). Our educational programme benefits from an advisory board consisting of mathematicians in industry. At this board's annual meetings we discuss aspects of the study program and share ideas for improvement. Next to current collaborations listed below, DIAM will focus on larger scale projects with industry.

  - Dutch knowledge infrastructure
  - Fintech
  - Energy transition sector
  - Healthcare sector

- **Convergence**
  - DIAM is active within 4TU.AMI (4TU Applied Mathematical Institute), where the applied mathematics departments of 4TU collaborate in research, education and valorisation.
  - User support staff for the DelftBlue supercomputer are embedded in DIAM. We are one of the initiators seeking to obtain an on-campus supercomputer with links to other universities' hardware and the supercomputers from Surf.
  - DIAM, Computer Science and Electrical Engineering has started the Powerweb centre, which has evolved into a successful Delft Institute.

- **Research themes**

  - **Health & wellbeing**
    - **Medical imaging**
      - Improving medical imaging by rapidly solving the Helmholtz equations
      - Creating sharp images with cheap MRI equipment, using advanced mathematical techniques
      - Improving image analysis via machine learning combined with mathematical methods
    - **Optimising treatments**
      - Optimising radiotherapy for cancer cure
      - Improving proton radiation treatment
      - Investigating blood flow in blood vessels, to enable better treatment of cardiovascular diseases

- **Responsible Digital Technology**
  - Developing reliable, open-source algorithms
  - Developing explainable and fair AI methods
  - Research into physics-informed neural networks (PINNs)
  - Improving the efficiency of algorithms and the application of green computing via GPUs and FPGAs

- **Risk analysis**
  - Causal statistical inference, survival analysis
  - Planning of ambulances and hospital logistics
  - Risk analysis for health

- **Energy Transition**
  - **Energy distribution and generation**
    - Improving power generation, and hydrogen gas storage and production
    - Improving models for nuclear energy generation
    - Interconnecting different energy networks in cooperation with EE and CS
    - Safety and expert judgement
  - **Climate research**
    - Development of better climate models using High Performance Computing models, statistical modelling and data assimilation. Collaboration with Deltares, KNMI, RIVM and Nanjing University of Information Science & Technology (specialised in meteorological and climate research).

- **Personal grant**
  - Using the opportunities available for colleagues to obtain personal grants on a national (VENI, VIDI and VICI) and international (ERC) level. To help achieve this goal, a funding committee was appointed to advise the department MT on promising fits for colleagues with specific personal grants, and to streamline individual support in writing proposals and preparation for interviews. ■

Computer Science

The phenomena of ‘datafication’ and ‘AI-zation’ are accelerating as we seek to quantify everything through data, and as we automate more decision-making processes based on data. Computer science as a research field has gained strategic importance since these phenomena have entered all of our lives, and research in computer science sits at the heart of technological developments underlying these phenomena. TU Delft Computer Science operates at the forefront of these developments, aiming to help society at large by enabling it to realise maximum benefits while protecting it from potential risks.

We are already the largest in the Netherlands, and on our way to growing even further. This will help to better meet increasing societal demand for socially responsible computer science engineers, and also contribute to computer science education for all engineers. Alongside this, we are aiming to further expand our disciplinary scientific frontiers, crystallising our strong and recognizable scientific focus and profile, and strengthening our role as a multidisciplinary collaborator across all engineering and other sciences.

KEY AMBITIONS

- *To conduct world-class research in selected core computer science areas*
- *To maximise opportunities for socio-economic impact from computer science research*
- *To provide rigorous, research-inspired engineering education in computer science*
- *To contribute to an international academic culture that is open, diverse and inclusive, and which offers openly available knowledge.*

> 'Achieving our scientific goals depends critically on suitable lab facilities and computing infrastructure'

Research challenges

Decision support
Devising, implementing and evaluating fundamental (classical and data-intensive) AI solutions. It aims to improve machine-level processes involving humans, and support them in making decisions.

Data management and analytics
Enabling humans to handle large quantities of data efficiently, to gain insights into and to analyse complex (big, unstructured, distributed, heterogeneous, web) data, and to understand, explain and justify AI decisions.

Software systems engineering
Bringing together expertise in the areas of software engineering, programming languages, and software reverse engineering. Aiming to develop new ways to safeguard key quality attributes of complex software systems, such as robustness, reliability and evolvability.

Networked and distributed systems
Devising, implementing and analysing fundamental algorithmic and systems concepts for distributed and networked systems.

Security and privacy
Targeting foundational computer science challenges in security and privacy, namely showing rigorously that a computer system is inherently (in)secure, along with the maturing of design-for-security and privacy methodologies.

Research infrastructure

Achieving our scientific goals depends critically on suitable lab facilities and computing infrastructure. Past investments in building up and maintaining such resources have resulted in the Insyght Lab, and the Distributed ASCI Supercomputer (DAS) and ES (Embedded Systems) lab facilities. Read more in the *State of the Art Facilities* section.

Because Computer Science research depends increasingly on computing, storage, and software infrastructure, continuous investments are needed to facilitate research at scale. However, merely investing in hardware infrastructure is not enough. Substantial software development capacity is also needed, to support researchers in creating, maintaining, and operating (open source) software tools and services – for the research community and society alike. We have plans to build up and structurally maintain a pool of software engineers as part of our staff formation. This will allow us to undertake software development and consolidation for research, and to build up and maintain our educational software infrastructure, facilitating the use of a growing computing infrastructure by researchers.

KEY AMBITIONS

The Department of Intelligent Systems (INSY) research mission is to enable human and machine, in close cooperation with their environment, to deal with the increasing data volumes and complexity and to manage the growing role of AI-driven decision-making systems. The department pursues that mission by integrating fundamental research, engineering and design within the interlocking fields of data processing, interpretation, and visualisation, and interaction with data, using model- and knowledge-based methods and algorithms. knowledge.

Intelligent systems

Focus areas

INSY research is inspired largely by challenges from the domains of:

- Social media and entertainment
- Health and wellbeing
- Agriculture
- Security and privacy in cyberspace
- Cultural heritage
- An inclusive and responsible digital society

Research challenges

INSY is active in all five joint computer science research themes. In particular, we address:

- **Decision support** – interactive and hybrid intelligence, computer vision and machine learning, recommender systems, conversational AI
- **Data management and analytics** – bioinformatics, content generation and data visualisation, data analysis and process modelling in complex networks
- **Security and privacy** – AI for intrusion detection and prevention, security of AI, and privacy protection

Impact on society

Our research helps people and society to handle digitalisation well, benefiting from advantages and mitigating disadvantages. We build on our extensive collaborations with high-tech companies, research institutes, government, and policy makers, and we are also investing extensive effort in public outreach. INSY explains and discusses science with a broad audience, especially in the context of complex societal debates in the domain of AI. Professional education is an important tool in transferring our knowledge to a non-academic audience, and a good example is our leading role in the Cybersecurity Academy in The Hague. This now has a professional cybersecurity master, organised by us together with Leiden University. The department also plays a leading role in regional, national and European initiatives, most notably in the Dutch AI Coalition (NLAIC) and the AINed foundation.

> 'We build on our extensive collaborations with high-tech companies, research institutes, government, and policy makers'

Innovation

- **Strategic collaborations**
  Our close ties with society are reflected in our strategic collaborations with socio-economic partners, including large joint projects and initiatives. Our main strategic partners for the upcoming period include:
  - NWO LTP Plant XR (Agro sector)
  - ICAI labs
  - Medical Delta (Erasmus MC, LUMC, Leiden University)
  - Government, incl. National Police
  - Cybersecurity Academy The Hague.

- **Convergence**
  Within the health sector, INSY plays a key role in the HealthTech convergence, established together with the Erasmus University and EMC. This offers unique possibilities for our work on bioinformatics and AI for medical applications. Our contribution to the health sector is also given shape through our involvement in the Medical Delta program, established together with Leiden University and LUMC.

- **Personal grants**
  Because of the need to strengthen foundational research in our focus domains, INSY invests continuously to support frameworks that raise success rates for ERC and NWO personal research grants. Such grants enable a focus on application-independent, long-term and high-risk-high-gain research problems, and they form an important part of the department's project portfolio. We help staff members to optimise their activities along the entire grant-application pipeline. That starts with help thinking about a suitable topic, refining it through discussion in various internal ad-hoc committees, moves on to writing the proposal with the help of experts (possibly from external companies), and concludes with practicing for an interview with the committee. We expect the success rate of acquiring personal grants to continue to grow as a result.

> 'Within the health sector, INSY plays a key role in the HealthTech convergence, established together with the Erasmus University and EMC'

Software Technology

KEY AMBITIONS

The research mission of the Department of Software Technology (ST) is to advance the design, engineering, and analysis of complex, distributed and data-intensive software and computer systems. Society is on its way to being completely dependent on such systems – such as online payment systems, smart grids, smart cities, and self-driving cars. We seek to contribute both to the foundations of software and computer systems, and to the understanding of their operation. Research is therefore both fundamental and experimental – designing algorithms and abstractions, developing new concepts and theories, and identifying principles, and also engineering and analysing the behaviour of actual systems.

Focus areas

- Algorithmics
- Distributed systems
- Embedded and networked systems
- Programming languages
- Software engineering
- Web information systems

Research challenges

ST is active in all five joint computer science research themes. In particular, we address:

- **Decision support** – intelligent agents, user modelling
- **Data management and analytics** – data engineering
- **Software systems engineering** – software analytics, AI for software engineering, language engineering and software verification
- **Networked and distributed systems** – distributed trust, Internet-of-Things, big data processing and visible light communication
- **Security and privacy** – AI-based testing for secure systems

Impact on society

Our research is a direct enabler of digitalisation, of industrial sectors, and of society at large. We collaborate with organisations in software- and data-intensive sectors, including the tech sector itself as well as finance, transport and logistics, energy, education, and smart cities.

> 'Our research is a direct enabler of digitalisation, of industrial sectors, and of society at large'

Innovation

- **Strategic collaborations**
  - The information technology sector
  - The financial sector
  - The national Innovation Center for AI (ICAI), through individual labs as well as in the NWO Long Term Program ROBUST
  - The Dutch government (Ministry of the Interior) through our work on distributed trust and digital identities.

- **Convergence**
  The department of Software Technology is involved in the LDE Center for Education and Learning (LDE-CEL), the LDE Bold Cities initiative. We participate in the HealthTech convergence, and we are a prominent player in bringing together all research in Artificial Intelligence across the three universities.

- **Personal grants**
  We have been highly successful in obtaining NWO Veni, Vidi, and Vici grants. Such grants provide the possibility to focus on application-independent, long term research problems, and form an important part of our project portfolio. We will continue to target personal grants, both from NWO and ERC. ■

> ‘We have been highly successful in obtaining NWO Veni, Vidi, and Vici grants’

The department of Electrical Sustainable Energy (ESE) conducts research aiming to accelerate the all-important energy transition towards sustainable energy. This includes research on electrical energy generation from renewable energy sources, along with its transmission, distribution, storage, and consumption. We design and fabricate high-performance, low-cost multi-junction photovoltaic (PV) cells and power electronics devices for integration in future power networks. We also work on systems that generate electricity using sustainable PV and wind technologies, high-voltage and direct-current transmission, and intelligent power management for increasing energy efficiency.

Electrical Sustainable Energy

Our focus is on system integration of new components into existing and/or future energy systems. The large-scale introduction of renewable and distributed energy sources is imminent, and so we employ multidisciplinary 'system of systems' approaches in order to study the technical, economic and societal performances of a future electricity system. By working on this energy transition, ESE contributes to tackling important societal challenges such as climate change and environmental pollution. We play a leading role in the EEMCS thematic line 'Energy Transition'.

KEY AMBITIONS

- *Affordable fossil-free energy for all consumers*
- *Digitisation of the energy system*
- *Maximising the area for energy conversion*
- *Reducing energy waste*

Focus areas

- Photovoltaic technology
- Power electronics and storage
- Digital technologies for energy systems
- High voltage technologies

Research challenges

Photovoltaics

Solar energy is the largest available primary energy source. To use it efficiently and sustainably, we focus on further development of photovoltaic technology to make it intelligent, invisible, and circular in the future – so that every suitable surface can be used for electricity generation. Research is focused on innovations from material science, physics of multi-junction solar cells, and electronics at the module level. This translates into building expertise in six research areas: (i) solar energy materials, (ii) hybrid tandem devices, (iii) smart and multi-functional modules, (iv) X-IPV systems, (v) photovoltaic multiscale modelling, and (vi) circular photovoltaics. Excellent infrastructure is available in the TU Delft PV Technology Center (theme lab in the EKL Lab) for preparing new, sustainable materials and fabricating hybrid tandem solar cells based on silicon and perovskite absorber materials. The ESP Lab houses measurement, test, and module manufacturing equipment.

> 'To use solar energy efficiently and sustainably, we focus on further development of photovoltaic technology to make it intelligent, invisible, and circular in the future'

Digital technologies for energy systems

Sustainability is the new requirement for our power system, turning the traditional dilemma of reliability vs. affordability into a trilemma. Decarbonisation leads to changes in generation, transmission, interconnection, distribution, and use, and most new assets are interfaced via power electronic converters. Such changes mean unprecedented operating conditions and steady-state and dynamic performance. We need a future system with properly designed controls to cope securely with diverse operating conditions and disturbances – and digitalisation has a crucial role. The future power system will use data extensively to make better and faster decisions in keeping the system sustainable, reliable and flexible, enabling all users to become active players. Research is focused in four areas: (i) future-proved power grids, (ii) digital energy, (iii) integrated energy systems, and (iv) reliability and resilience.

Power electronics and storage

Electricity from RES is coupled to the electricity grid by power electronics components. Novel power-electronics converters for broad scale of applications with high efficiency, modularity and flexibility are designed and tested. Weather-dependent RES demands a secure and more flexible energy supply, and a promising approach to keep the future energy system stable, reliable, and resilient is a decentralised power-electronics based system based on microgrid networks with distributed electricity generation. Research into microgrid components and networks focuses on local electricity generation from solar energy and the adaptation (conversion) of sustainable electricity for different applications such as household consumer devices, electric vehicles, heat pumps, batteries and electrochemical processes for storage. A research challenge is the balance of power generation and consumption, where PV technology may generate excess amounts of electricity or where multiple electric cars may charge at the same time. ▸

High voltage technologies

One important feature of energy transition in the electric power system is the implementation of new High Voltage Direct Current (HVDC) components and systems. These have enhanced bulk power transmission capability; enabled more effective transmission over long distances (including long subsea cables); boosted the integration of large-scale renewable energy sources (GW-scale solar and offshore wind plants); and improved the flexibility and controllability of Alternating Current (AC) systems. High Voltage technology supports the emergence of an AC/DC grid dominated by hybrid power electronics. This will minimise environmental impact and massively strengthen, renovate, and expand the grid. Research focuses on: i) test methods for 'new' stresses on medium and high voltage insulation, ii) monitoring and diagnostic methods to assess the consequences for ageing and reliability in existing and new power system components based on data and AI, iii) innovative insulation concepts and materials that can be applied for medium- and high-voltage power electronics building blocks, including high frequency transformers, iv) asset management and innovative environmentally friendly alternatives for SF_6 and v) optimisation of high-voltage components based on testing and analysing their performance.

Impact on society

Mitigation of global warming by accelerating the energy transition through innovative solutions that deliver sustainable, affordable and reliable energy for everyone.

Innovation

- **Strategic collaborations**
  - Grid companies such as Transmission System Operators (TSOs) and Distribution system operators (DSOs)
  - Testing, Inspections & Certification organization
  - Power electronics companies
  - Electric power generation
  - e-Mobility and electric charging companies
  - Knowledge infrastructure (TNO)
  - Government, municipalities

- **Convergence**
  The digital transformation is irreversible and rapid, and has changed much of the past decade. Digitalisation offers great opportunities as well as big challenges, and there is currently a global race for leadership in this field. Focusing on a knowledge cluster that can resolve socio-economic, security and sustainability problems with the help of AI is essential for our country. Within the AI, Data, and Digitalisation theme of 'Convergence', the sub-theme Energy and Sustainability is closely linked with the activities of our EEEMCS theme Energy transition.

- **Research infrastructure**
  - ESP Lab (including 'Control Room of the Future')
  - TU Delft PV Technology Center (theme lab in the EKL laboratory)

- **Research topics**
  - Photovoltaics, photovoltatronics, circular photovoltaics
  - Energy conversion: power electronics and electro-mechanics,
  - Reliability of power electronics
  - Design & operation of future power system
  - Microgids, hybrid AC/DC grids
  - Storage: batteries, hydrogen
  - Digitalisation, AI, machine learning
  - Protection, resilience, cyber security of power systems
  - Integration of energy networks.

> 'One important feature of energy transition in the electric power system is the implementation of new High Voltage Direct Current (HVDC) components and systems'

Microelectronics

Microelectronics is one of the main drivers behind the digital revolution that is transforming our world. The research and educational activities of the department of Microelectronics (ME) span all aspects of electronic engineering – from electromagnetics and signal processing to hardware design, and from microfabrication to the realisation of complete radar arrays.

Our research is bundled into three main themes: health and wellbeing, autonomous sensor systems, and next generation communication and sensing. These themes cover topics such as the design and development of organs on chip; micro-electromechanical systems (MEMS); analogue and digital circuits for smart sensors; biomedical implants and wireless communication systems; signal-processing algorithms for communication and biomedical signals; and microwave and terahertz systems for remote sensing and radio astronomy.

KEY AMBITIONS

- *Increasing the energy efficiency of radio front-ends intended for 5G and beyond*
- *Applying AI to the extraction of clinically relevant indicators from biomedical parameters acquired via wearables, ultrasound and MRI*
- *Realising wireless communication and radar systems that combine our expertise in electromagnetics and analog/digital IC design*
- *Successfully managing the transition from EKL/Kavli to a new Campus Baseline lab*
- *Developing the viable organ-on-chip platforms that will enable truly personalized medicine*
- *Developing autonomous systems that will combine sensing, navigation, energy harvesting and wireless communication*

Focus areas

- Health and wellbeing
- Autonomous sensor systems
- Next generation communication and sensing

Research challenges

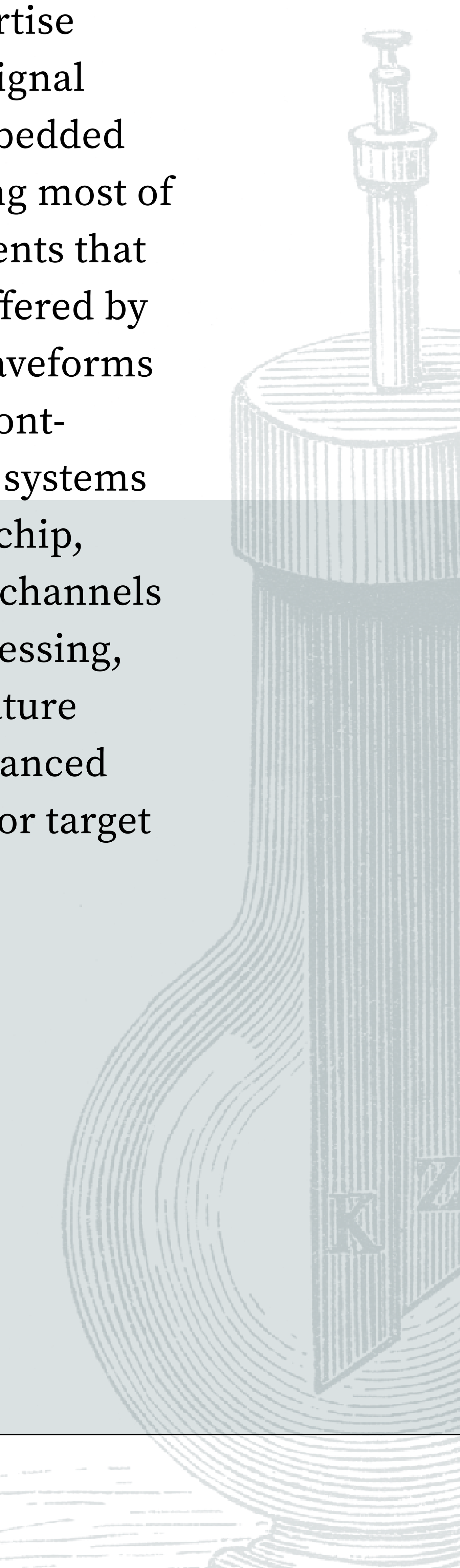
Next generation communication and sensing

Next-generation wireless communication systems (5G and beyond) come in two flavours. They can provide ultra-high data rates in combination with smart antenna systems, or they can enable ultra-low power sensing applications for a large number of devices (IoT). When used in a control loop (e.g. remote surgery or autonomous driving), strict demands on response times and reliability are key. Massive antenna arrays, waveform agility and multi-channel signal processing are considered to be the enabling technologies. Spectrum scarcity will demand dynamic spectrum usage based on distributed system management, cooperative spectrum sensing and cognitive radio concepts, and motivate exploration of frequency spectrum above 30 GHz.

Based on similar RF technologies, active sensing systems such as radar and sonar aim to build situation awareness using electromagnetic and acoustic waves. Next generation radar, in addition to frequency diversity, will also exploit spatial diversity by combining relatively small microwave sensors, distributed over multiple nodes, achieving wide coverage with high 3D-resolution in space and 3D-resolution in velocity . For example, signals from multiple radars on each car might be complemented with radar signals from other cars, building a complete picture of the situation on the road and enabling cooperative driving. Other applications are high-resolution weather monitoring near airports, coastal surveillance (above and under the sea surface), and crowd and human activities monitoring.

> 'We aim to work on Digital RF, replacing most of the bulky analogue circuits with digital equivalents that benefit from the exponential miniaturisation offered by Moore's law'

This wireless communication–sensing priority axis is very much system oriented and combines expertise on electronics with that of electromagnetism, signal and information processing, networks, and embedded systems. We aim to work on Digital RF (replacing most of the bulky analogue circuits with digital equivalents that benefit from the exponential miniaturisation offered by Moore's law). Also included are new wireless waveforms and transmission schemes for multi-channel front-ends, and high frequency (mm-wave/terahertz) systems that promise massive phased arrays in a single chip, providing thousands of independent wideband channels simultaneously. Regarding signal and data processing, we have a focus on multi-thread processing, feature fusion, distributed information processing, advanced statistical techniques (incl. machine learning) for target classification and sensor management.



Health and wellbeing

The health and wellbeing theme addresses challenges related to the design and implementation of miniaturised biomedical systems for precision medicine, personalised care, and healthy lifestyle. It spans material research and technology development, through to device and circuit design, to signal processing and system implementation. We cover both in-vivo and in-vitro devices and systems, as well as advanced imaging and diagnostic instrumentation such as low-field MRI and functional ultrasound. Technological challenges are miniaturisation, accuracy and reliability, energy efficiency, biocompatibility, manufacturability and costs. The aim is to contribute to faster and more accurate diagnostics, to advanced therapy, to an improved quality of life (also for healthy people to improve productivity and overall societal participation), and to better care that is more efficient and less costly. Examples of programmes within the teams are the hDMT initiative (organ-on-a-chip platform); intelligent catheters for intervention; and bioelectronic medicine / electroceuticals.

Autonomous Sensor Systems

Sensor systems are used for measuring, monitoring and control. They are sensor systems in which distributed sensor nodes contain local signal and data pre-processing capabilities. Self-testing, auto-calibration, filtering, and data compression within sensor nodes – without or with very limited external intervention – is therefore crucial. In many applications, wiring is not possible, unreliable or undesirable, which makes the powering of sensors a major issue and calls for ultra-low power electronics and smart design at all levels in the system.

> 'With TUE we collaborate on a programme to realise a low-frequency radio telescope in space using a swarm of nano-satellites (OLFAR)'

In IoT applications, sensors operate in a network. Limited power resources favour power-efficient communications. Sensors can communicate only with neighbouring nodes, creating a dynamic and complex network that relies on self-organising and self-healing capabilities. Further, data without location and time stamps is meaningless; by exchanging information with local neighbours, all sensors in the network can become synchronised and localized. In biomedical applications, the sensors need to be miniaturised and packaged to be bio-compatible or implantable, for example with smart (multi-modal) catheters or electroceuticals, which combine sensing, local data processing, and actuation.

In other applications (e.g. autonomous driving or flying enabled by a variety of radar sensors distributed over many nodes), the focus is on robustness and reliability, in the context of a very dynamic network, and optimal fusion of different sources of information. With TUE we collaborate on a programme to realise a low-frequency radio telescope in space using a swarm of nano-satellites (OLFAR). Emerging technologies such as neuromorphic computing and structured data science are expected to play an important role in future. ■

Innovation

- **Strategic collaborations**
  - Semiconductor industry
  - Semiconductor equipment manaufacturers
  - Communication technology sector
  - Dutch knowledge infrastructure
  - NeuroTechNL
  - Medical Delta
- **Convergence**
  - Strengthening the collaborations with Medical Delta (cardio, neuro).
- **Personal grants**
  - The department has been quite successful in attracting personal grants from NWO and the ERC. Building on this, a committee has been set up to identify suitable candidates and to peer review the resulting proposals.

Quantum computing and low-energy computing are in very early stages, and entire infrastructures will be needed as they develop. Our research on computer architectures targets the invention, design, prototyping and demonstration of disruptive computing accelerators/engines. It makes use of unique features of emerging devices (quantum bits, memristors, spintronics, graphene, etc.), while mainly targeting energy-constrained low-granularity computing for many edge applications. These include AI applications such as personalised healthcare, smart environments and drones.

Quantum & Computer Engineering

The department of Quantum & Computer Engineering (QCE) adapts a holistic approach, addressing the whole computing engine design stack (i.e. technology, circuit design, architectures, compilers, algorithms and applications) in order to maximise computing efficiency. The main focus is on the middle layers (circuit design, architectures and compilers). This research goes hand in hand with research into the dependability aspects of such designs such as testability and design-for-testability, reliability and security. The important aspects of design, management and control of network architectures are exploited through the use of network science and artificial intelligence. Results are used not only in the field of computer architectures, but also in a variety of critical infrastructure domains, such as telecom, power grids, transportation and water distribution.

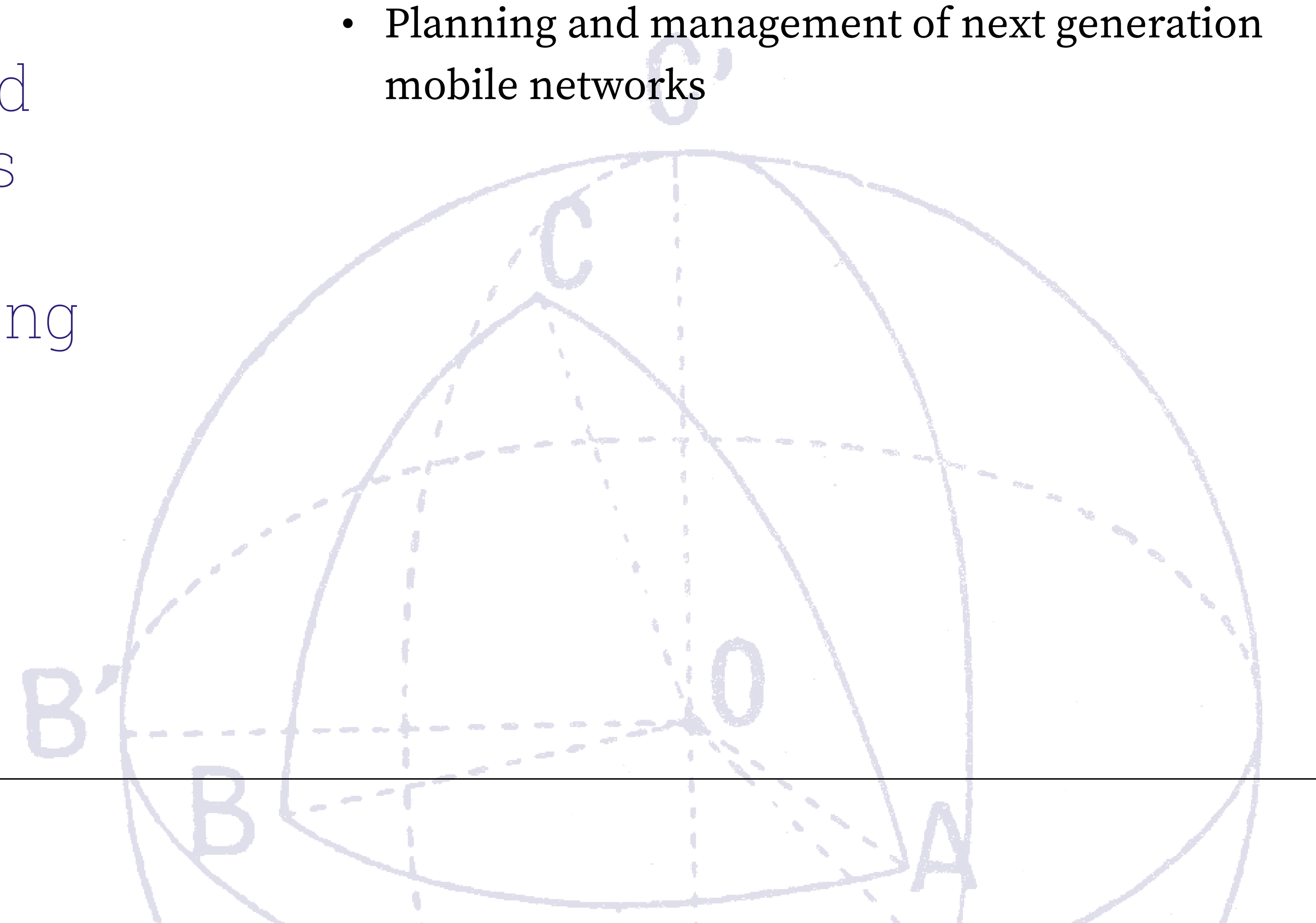
KEY AMBITIONS

- *Energy-constrained computing engines for a wide range of edge applications, including AI, such as personalised healthcare, smart environments and drones*
- *Bringing quantum technologies out of the research labs into the field, to enable them to tackle relevant societal challenges*
- *Enabling resilient complex interdependent critical infrastructures*
- *Development of realistic network models for virus spread that can mitigate the next pandemic.*

> 'Recent developments in materials, e.g. graphene, and devices such as memristors and magnetic junctions, provide premises for pursuing unexplored computation avenues'

Focus areas

- Architectures and circuits related to:
  - Neuromorphic computing
  - Approximate computing
  - AI and big data
  - Edge computing
  - Computation-in-memory
- Application of unique features of emerging devices to computing engines (e.g. quantum bits, memristors, spintronics and graphene.)
- Engineering challenges such as scaling up of quantum-enabled systems and applications
  - Fabricating and integrating new materials and devices
  - Designing and implementing (cryo-CMOS) interface electronics for those quantum devices
- Quantum computing architectures
- Quantum sensing devices
- Resilient complex interdependent critical infrastructures
- Spread of epidemics over networks
- Planning and management of next generation mobile networks



Research challenges

Unconventional electronics and computing systems

Research focuses on developing new concepts at device, circuit architecture, processing, communication, integration, software and algorithmic/protocol levels. This aims to enable new (non-Von Neumann) computing paradigms, and to demonstrate the potential of highly improved performance for generic or specific applications. Our work includes quantum research, in close cooperation with the QuTech research centre in Delft and associated companies. Regarding quantum computers, one research line is focused on scalable electronics for sensing and actuating qubits at cryo-temperatures. Another research line focuses on defining a generic systems architecture from quantum programming languages to the quantum microarchitecture. We also research the fabrication and integration of new materials for fabrication of qubits. Bioinspired computation paradigms have so far had only limited practical impact, mainly because CMOS (the mainstream fabrication technology) is not suitable for their realisation, although they have been providing a natural foundation for Boolean logic implementations. However, recent developments in materials, e.g. graphene, and devices such as memristors and magnetic junctions, provide premises for pursuing unexplored computation avenues. Network architectures and services (NAS) – the NAS section contributes to the fundamentals of network science, especially under the following themes: development of the theory of non-Markovian epidemic processes (to tell how long a pandemic will last and when a peak will occur); geometric embeddings of networks based upon complementarity (as opposed to similarity) with an application to Science of Science; exploration of the relationship between network science and machine learning methods; various aspects of interdependent complex networks, such as robustness, controllability and recoverability; development ML/AI methods to be used in the context of next-generation mobile networks.

Impact on society

Enabling optimal solutions of complex problems that conventional computers cannot address
There are many infeasible applications whose solutions would require thousands of years using traditional computers but which a quantum computer could solve in days if not hours. Examples include drug design & development, financial modelling, logistic optimisation and weather forecasting.

Enabling cost-effective computation solutions for currently infeasible AI edge applications
Many applications depend on a single foundation: ultra-low-power computing engines. These include edge computing, edge analytics, edge intelligence and edge real-time decision making. This is true irrespective of whether the application domain is related to personalised healthcare, smart homes, drones, environmental monitoring or smart agriculture.

Contributing to a greener world and prevention of climate change
We contribute to bringing greener digital solutions to the market by targeting reduction of energy use by at least 100x per operation, especially in energy-intensive applications such as machine learning and big data.

Network architectures
Our society depends increasingly on the proper functioning of a number of complex interdependent critical infrastructures, such as telecom networks, logistic networks, transportation networks, power grids and more. A failure in one infrastructure can lead to severe consequences in other infrastructures, for instance during the obstruction of the Suez Canal in 2021.

Our research into the design, management and control of complex interdependent critical infrastructures will make these networks more robust, resilient, efficient and reliable. This will make our society less vulnerable to failures, attacks and pandemics. ■

Innovation

- **Strategic collaborations**
  - Semiconductor manufacturers
  - Information technology and software sector
  - Communication technology companies
  - Dutch knowledge infrastructure
- **Convergence**
  - QCE is on the board of the Dutch Network Science Society, the Dutch Chapter of the worldwide Network Science Society
- **Personal grant**
  - ERC Advanced Grant 'Virus Spread in Networks' (ViSioN) for Piet Van Mieghem.

State of the art facilities

ESP Lab

To keep our planet liveable, we need to make decisions quickly and take tangible steps toward a sustainable energy system – a system that is greener and smarter, and just as safe and robust as today's electricity grid. That system will allow everyone to connect their own solar panels and allow any vehicle to recharge at any time without problems. Making such a future reality rests on a great deal of research and innovation. In the Electrical Sustainable Power Lab (ESP Lab), researchers, companies, policy makers and business developers work together on the most crucial energy issues of our time. It is the ambitious organisation where our electricity grid is being prepared for the future. Dare to change energy!

> 'The ESP Lab is a unique combination of facilities: there is no other laboratory where these research set-ups combine forces under one roof.'

Fields of research

Photovoltaics

In order to generate enough renewable electricity from sunlight in future, we need more efficient and intelligent solar panels. The ESP Lab is working on this, and also on innovations to embed solar cells all around us and to connect them intelligently to the energy grid.

DC systems

The direct use of green direct current generated from renewable resources increases the stability and reliability of the electricity grid as a whole, and reduces inevitable energy losses involved in conversion to alternating current and reverse. The ESP Lab is designing future-proof components that can safely transmit, use, and where necessary convert green electricity as efficiently as possible, without losses.

E-mobility

One million electric vehicles are expected to be in use by 2025, with a huge increase in demand for electricity. The ESP Lab is studying how electrification of transportation fits into the electricity grid of the future. Our biggest challenges are storing energy, charging batteries more efficiently, and smart charging.

Intelligent energy system
In future, we will have to harmonise demand for electricity with huge fluctuations in supply. We are working on algorithms and technologies to protect, monitor and control the electricity grid.
Strength through collaboration – the energy transition is a complex issue that requires effort from all of us, and an integrated approach involving collaboration is indispensable. The ESP Lab allows researchers, companies, policy makers, business developers and social scientists to combine forces, in order to determine the route to our sustainable future. It is also a place where we educate young engineers to become future energy leaders, gaining crucial expertise for innovation in a world that never stands still.

Infrastructure
Our infrastructure allows research into many areas under one roof. It includes power generation, conversion and storage facilities, grid and microgrid components, power facilities for high, medium and low voltages, and extensive ICT facilities. The result is an ability to explore the generation, transmission and distribution of electricity, and its use by households and companies.

- Power-electronic systems
- Power system simulation
- High Voltage testing equipment
- Device characterisation
- Material characterisation.

Control room of the future
Digitisation is essential for modernising the electricity grid, but it also exposes vital infrastructure to cyber-attacks. In our 'control room of the future' we enhance the cyber security and resilience of the electricity grid.
Digital twin – the 'digital twin' is a computer simulation of the entire electricity grid of the Netherlands. Major and minor changes to the grid can be tested freely without damaging anything.

tudelft.nl/esplab

Control room of the future

The increased digitalisation of the power grid comes with its own set of cyber threats and risks. In TU Delft's Control Room of the Future (CRoF) the power grid gets put through its paces. This remarkable research facility offers both industry and academics unique opportunities to research, develop and test the integration of new energy management technologies into the smart grid.
So the CRoF is actually a testbed for dealing with all kinds of disruptions, including cyberattacks. Its ultimate goal? A power grid that is intelligent, resilient and cyber secure.

tudelft.nl/en/eemcs/research/facilities/esp-lab/infrastructure/the-control-room-of-the-future

PV Technology Center

The TU Delft PV Technology Centre researches innovations and developments involving future tandem solar cells. The facility enables researchers to work on new absorber and supporting materials, advanced passivation schemes and novel solar-cell architectures. Our equipment can be used to research novel materials and devices of benefit to many other disciplines at TU Delft such as photonics, microelectronics, batteries and quantum computing. Research infrastructure includes deposition lines for fabrication of silicon and perovskite solar cells on 6-inch substrates. An ability to process 6-inch wafers – a standard size for the PV industry – significantly bolsters the TU Delft PV experimental infrastructure and makes it industrially-compatible.

EKL / Cleanroom

The Else Kooi Laboratory (EKL) and Kavli Nanolab (KN) are two cleanrooms at TU Delft for micro- and nanofabrication. Integration into a Campus Baseline Lab (CBL) and a Business Lab (BL) brings important benefits. The CBL aims to provide micro- and nanofabrication capabilities that facilitate excellence in (sub)micro-fabrication oriented research, and the BL enables customers to test out concepts that may lead to business successes (up to and including small scale production). Together, they build a bridge between academic research and industrial innovation. The labs are superbly equipped for micro- and nano-manufacturing at the cutting edges of integrated circuits, micro-electromechanical systems and working with flexible substrates. The combination of these technologies is what makes the lab unique.

tudelft.nl/ewi/onderzoek/faciliteiten/else-kooi-lab

Radar Labs

Modern radar sensors must be not only detect, but also operate as multi-functional instruments. They have to detect, trace, classify and recognise targets, estimating and retrieving their parameters. Radar Labs includes multi-sensor facilities on the roof of the EEMCS building – most importantly the fully reconfigurable polarimetric wideband radars PARSAX and MESEWI; the radar facilities located at Cabauw, TARA and IDRA; and the antenna measurement chamber DUCAT. The labs also include a distributed radar system for the surveillance of the lower airspace (RAEBELL); automotive 77 GHz radars; a millimetre-wave and UWB indoor laboratory; a multichannel transmission MIMO radar; and a ground penetrating radar measurement site. This infrastructure is leading in Europe.

radar.tudelft.nl

High Performance Computing (HPC)

High Performance Computing (HPC) is a pervasive technology that contributes strongly to the excellence of science, education and innovation at TU Delft. It allows researchers and engineers to make better predictions of macroscopic properties, based on comprehensive multi-scale models across a multitude of length scales. A wide range of scientific and engineering questions cannot be answered without using HPC. Here are a few examples:

- How can we improve renewable energy systems such as solar panels and wind turbines, and integrate them into a power network?
- What's the impact of global warming on local climates and extreme local weather conditions?
- How can we unravel the mechanisms of disease and provide customised treatments for patients?

The Delft High Performance Computing Centre (DHPC) provides the facilities (hardware, software and training) that allow researchers and students to run complex analyses and simulations.

tudelft.nl/en/stories-of-support/kees-vuik-and-frans-broos

INSYGHTLab

The INSYGHTLab is a highly visible facility that hosts experimental installations for display and interaction hardware and software. This showcase facility focuses on interdisciplinary research into computer vision, interactive intelligence and visualisation.

Computer vision

INSYGHTLab hosts multi-camera experiments for 3D scene reconstruction, enabling the building of equipment for perception-related research. Research on the usage of these cameras and development of these new technologies will contribute greatly to televisions of the future. These new televisions could be highly interactive screens, giving spectators the sensation of being part of the actual scene.

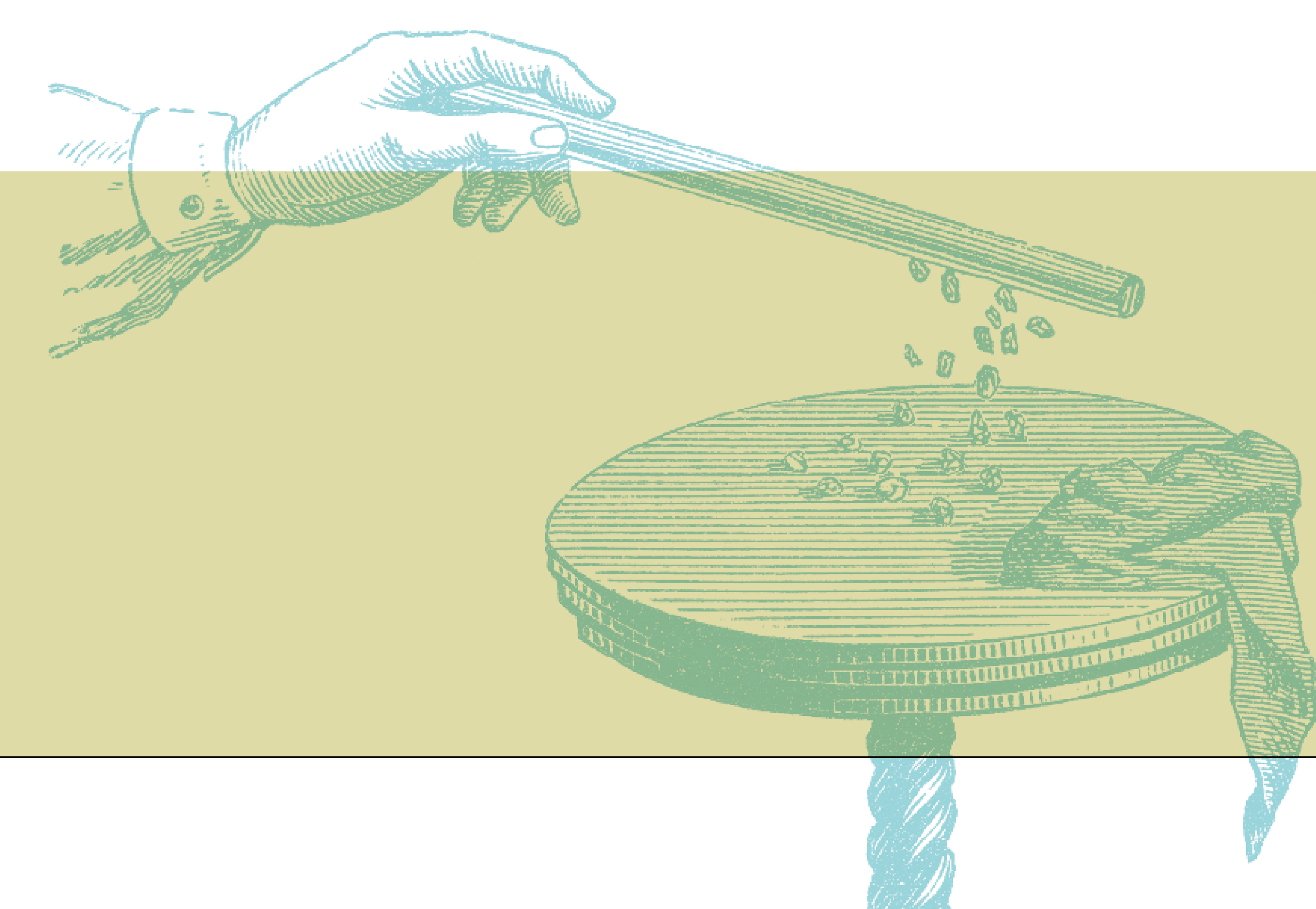
Intelligence

Humanoid robots are essential for the advancement of interactive robotics. Our lab works to create robot companions for children with chronic illnesses, and for the elderly to enhance quality of life and self-reliance. World-leading automated negotiation technology (GENIUS) is used to facilitate research into negotiation bidding and accepting strategies and opponent models. GENIUS technology underpins our negotiation support software, the Pocket Negotiator, which is currently being developed for the layman negotiator. INSYGHTLab offers all necessary facilities for the development of virtual reality exposure therapy for mental health issues such as fear of flying, post-traumatic stress and social phobia. This proven technology is brought from the lab to therapeutic centres, to benefit people requiring help for such mental issues.

Visualisation

The lab also marks the starting point of a competing and collaborating Interaction and Vision facility for other, similar-minded labs. By combining diverse set-ups and sharing the same physical equipment, (young) researchers can learn from each other's disciplines and expertise. The goal is to provide multi-media capable machines and software for multimedia content creation purposes.

tudelft.nl/ewi/onderzoek/faciliteiten/insyghtlab



Embedded Systems Lab

The Embedded Systems (ES) Lab is the ST department's main facility for developing custom hardware, which is especially instrumental for the Embedded and Networked Systems group. Many PhD and MSc students use the tools (e.g. soldering station, oscilloscopes, 3D-printer) to assemble proprietary PCBs and enclosures, creating functional prototypes that enable experimental evaluation of their designs. To support the research into Visible Light Communication, the ES Lab has been fitted with blackout curtains. For research into low-level (physical layer) communication protocols (e.g. LoRa) there are Software Defined Radio boards and power monitoring equipment. We plan to upgrade this equipment to ensure that we can also handle 5G (and beyond) networking chipsets.

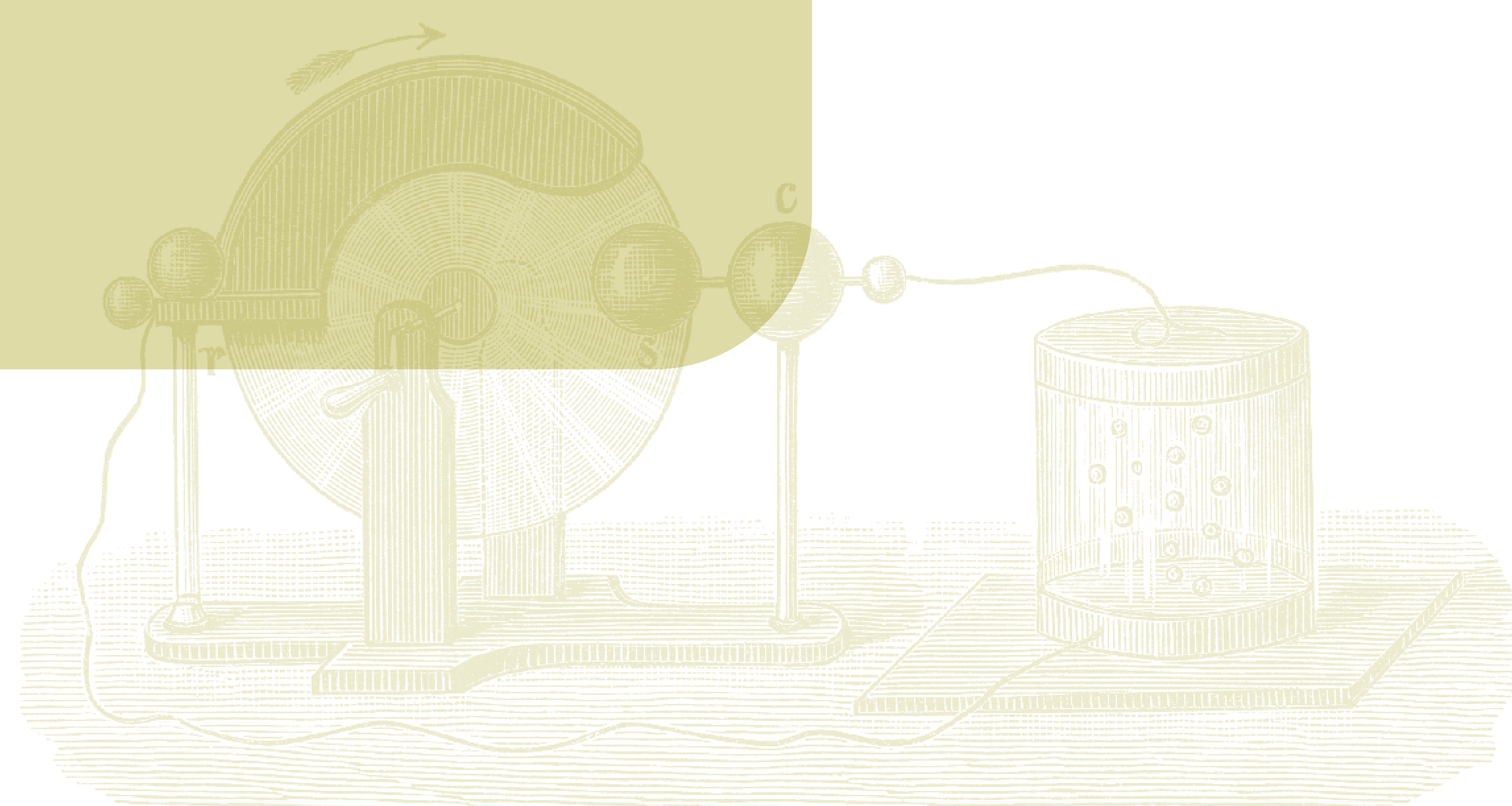
DAS

The Distributed ASCI Supercomputer (DAS) is a nationwide multi-cluster system dedicated to computer science research, installed by the Research School ASCI with funding from now (one cluster of which is located at EEMCS)e. It is currently in its sixth generation, and is instrumental in much of the research in distributed systems.

DoIoT Field Lab

Do IoT Fieldlab drives the acceleration of innovation in the field of Internet of Things (IoT). The latest generation of mobile communication (currently 5G) offers a great opportunity for the large-scale introduction of the Internet of Things. The fast connections, high reliability and short response times of 5G make it possible to bring new applications to the market in the areas of mobility, logistics, agriculture, health and safety. The Fieldlab supports the development of these new applications.
In short: Groundbreaking Internet of Things for a better society.

tudelft.nl/internetofthings/fieldlab



Colophon

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