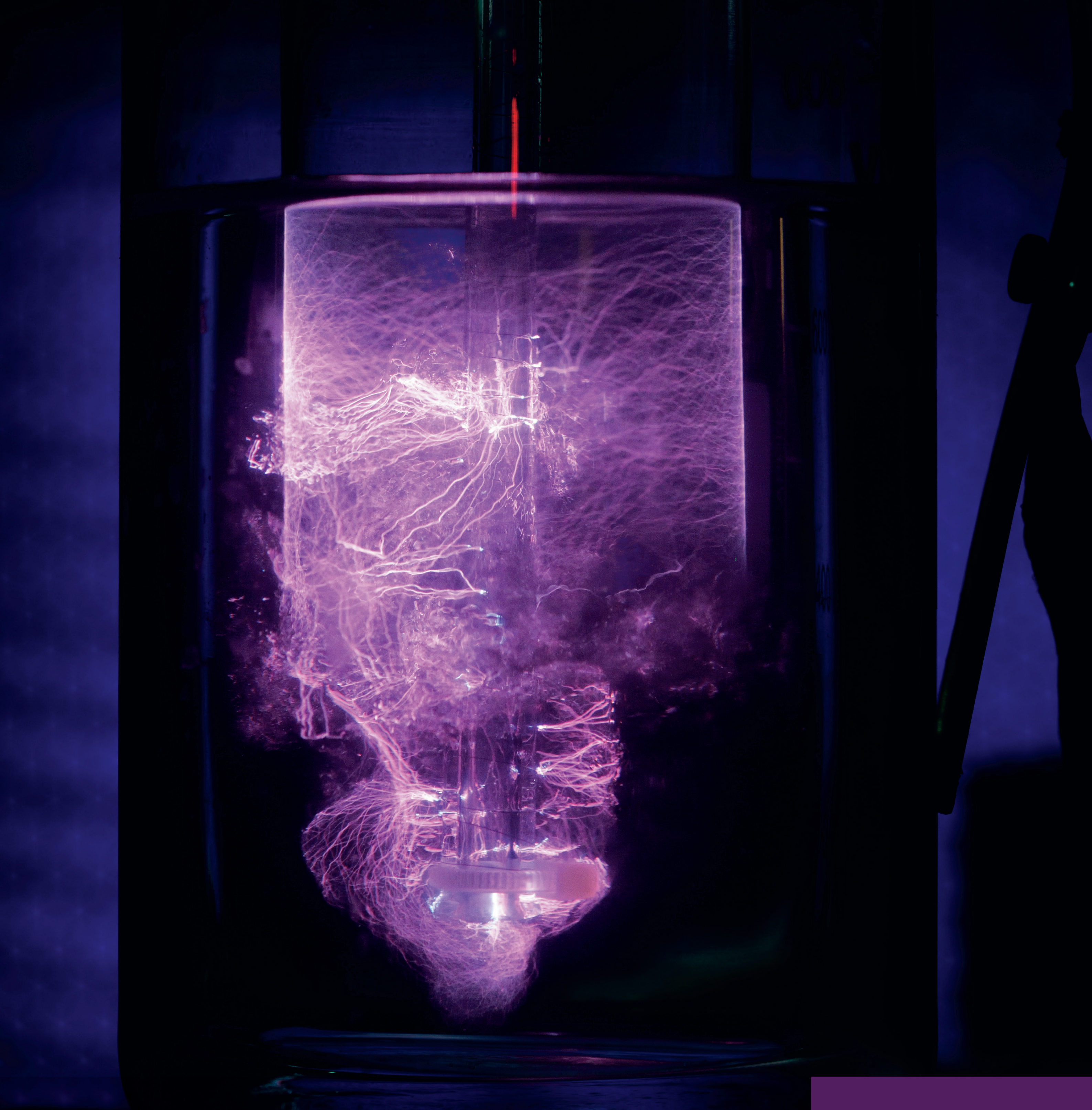

Strengthening the foundations of TU/e as a high-tech systems university: Engineering disciplines

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Front cover

The "goblet of fire": activation by electric gas discharge in water. Research conducted within the department of Electrical Engineering by Wilfred Hoeben. Application examples of this and related research are flue gas cleaning and waste water purification.

Photo by Bart van Overbeeke.

Strengthening the foundations of TU/e as a high-tech systems university: engineering disciplines

15 May 2019

1 Title

Strengthening the foundations of TU/e as a high-tech systems university: engineering disciplines

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4 Summary

Eindhoven University of Technology works at the forefront of science & technology, is leading in academia-industry cooperation and aims to strengthen the basis of science and engineering discipline to take the next step as the high-tech systems university of the Netherlands. As high-tech systems become more complex, are employed in a broader range of purposes and evolve towards applications that integrate digital, physical and chemical elements, a strong basis that allows for a convergence of these fields is necessary. To do so, in strengthening the disciplines of Mechanical Engineering, Electrical Engineering and Civil Engineering, TU/e focuses on three Cross-disciplinary Research Themes that enable the next step in high-tech systems: artificial intelligence in engineering, smart materials and energy & sustainability.

4.1 Mechanical Engineering

Impact

The energy transition, a sustainable mobility, closing material cycles and improving health care all require increased competences to devise materials, systems and devices. Mechanical Engineering offers a plethora of fascinating technologies for this purpose, spanning the full range from microscopic materials to complex machines. Mechanical Engineers develop new ways to understand, develop, design, construct, power and control complex systems and their constituting materials. In the Eindhoven-Brainport high-tech hotspot, Mechanical Engineers contribute significantly to the development of some of the most complex machines humanity ever made. Examples of recent break-through technologies can be found in the EUV lithography machines of ASML, MRI scanners produced by Philips and electron-microscopes of Thermo Fisher.

The above examples highlight the broad span of the discipline. In Eindhoven, research is being done in all these areas in full breadth. In the area of Thermo-Fluids Engineering, expertise on ultra-clean combustion technology is used to develop technologies to replace fossil fuels. Optimal energy storage materials and systems are designed based on deep knowledge of the physical processes of fluid flow, energy and matter exchange. In the area of Mechanical and Materials Engineering, materials, combinations of materials and material manufacturing techniques are developed with integrated multi-functional behavior, based on our world-leading expertise in multi-scale methods and fundamental knowledge on structure-property behavior of materials. In the area of Systems and Control Engineering, scientific and technical research is directed towards high-tech equipment and complex interacting (autonomous) systems. The ability to control these with extreme precision and speed opens up new applications. Examples are automated transportation systems, robotics for care, cure & agriculture.

The TU/e department of Mechanical Engineering has strong and numerous industrial collaborations, within the Eindhoven-Brainport area and outside. The (Brainport) industry has a huge attraction on our students. Our research connects well with the *Topsectoren* 'High-tech Systems & Materials', 'Chemistry' and 'Energy' and with the *Nationale Wetenschapsagenda*, especially with routes 'Energy Transition', 'Circular Economy', 'Materials', 'Smart Industry' and 'Logistics & Transport'.

Quality

The Eindhoven department of Mechanical Engineering belongs to the leading mechanical engineering departments in the world and is highly ranked in international university rankings, e.g. it is ranked 44th on the QS-ranking. Most research groups received (close to) excellent scores, with 3 groups having a maximum score of 5 in all 4 categories in the last international research assessment (2003-2012). The researchers have an outstanding scientific reputation and several are leaders in their fields. Many of them received awards (e.g. 2 are Simon Stevin Meester, 6 received ERC Starting Grants, 1 ERC Advanced Grant, 1 ERC Proof of Concept Grant; 2 VICI, 8 VIDI & 8 VENI grants).

Ambitions

In line with the profile of the university and it ambition to focus on artificial intelligence in engineering, smart materials and energy & sustainability, the department has the ambition to strengthen selected parts within the three departmental sub-disciplines:

- Within 'Thermo-Fluids Engineering' we propose to strengthen the *zwaartepunt* 'Multiphase flows for low carbon systems' in order to explore the exciting new field of metal fuels as compact CO_2-free recyclable energy carriers and the use of porous media as efficient energy storage systems.
- Within 'Mechanical and Materials Engineering', the department will focus on the *zwaartepunt* 'Designer & hybrid multifunctional materials'. Here, the department targets the investigation of

'Designer materials', i.e. materials that change morphology and properties over time in a controlled manner, and 'Hybrid materials', which are multi-materials with interfaces, combining engineering and natural materials, as well as the interface between them. Integration of the two classes above leads to 'Multifunctional materials', i.e. 4D materials and functionally integrated systems where the materials become the system.

- Finally, within 'Systems and Control Engineering' the department aims to strengthen the *zwaartepunt* 'Interactive and Smart Autonomous Systems'. Within this area, the department aims to advance science and technology on autonomous systems which requires breakthroughs in sensing, control, (world) modeling, human-machine interaction, hardware & software design, and (big) data management and algorithmic design.

These 3 *zwaartepunten* align perfectly with the 3 Cross-disciplinary Research Themes with which the engineering *sectorplan* aims to strengthen TU/e as thé High-Tech Systems university in the Netherlands. To make these ambitions come true, we apply for 14 new positions, extending the 77 which currently shape the discipline in Eindhoven. This will enable TU/e to push the boundaries of our knowledge on energy, high-tech materials and controlled high-tech systems.

4.2 Electrical Engineering

Impact

Electricity is the world's most versatile form of energy, the prime way to carry information, and the essential ingredient of most technology related to both. TU/e has established a solid department of Electrical Engineering which covers the breadth of this field and has an extensive network of research partners, academic as well as industrial. Electrical Engineering at TU/e has become increasingly intertwined with other disciplines such as physics, material science, computer science and mechanical engineering, blending in application areas such as energy, healthcare, mobility and transport, safety and security, vitality and sports. This unique network brings the synergy between the various parts of the discipline to life, and finds a logical extension in the cross-disciplinary themes of TU/e as *the* Dutch High-Tech Systems university.

Electrical Engineering in Eindhoven has a global leading role in integrated photonics: light-based integrated circuits combined with electronics to drastically increase speed as well as reduce energy use. We play a prominent role in wireless infrastructure and in providing technology for clinical support, outperforming humans in cancer diagnosis. The work on high performance equipment for industrial automation and on smart electricity grids is also world leading. In all these areas, our activities incite start-up companies.

But it is not research accomplishments that impact society most. It is our graduates: our young electrical engineers are in great demand, are valued highly for their engineering knowledge and skills, and for their abilities to work in multidisciplinary teams.

Quality

The quality of the research is confirmed by research evaluation (most recent: 2017) and appears from the steady ascent of staff to IEEE-fellow rank, by national and European grants, by the amount of 2nd tier funding (*Zwaartekracht* programs 'Integrated Nanophotonics' and 'Networks', 2013) and 3rd tier funding (17 M€ per year from 2016 to 2018).

Ambitions

As described in the *Sectorbeeld* in more detail, the discipline as a whole aims to strengthen the coherence of the knowledge and expertise we gather from our research, because it is the foundation for the education we provide and for our relevance to society in many application areas. Knowledge from relatively unrelated application areas becomes powerful by integration and abstraction into a comprehensive set of insights and skills. The reinforcement of our basis will allow us to explore frontiers in current and new research areas, from fundamental to applied, and to present a coherent and up-to-date educational program to our students. TU/e is located in the Brainport region which provides fertile ground for these developments.

In particular, we wish to achieve knowledge integration in the following *focusgebieden*:

- In the area of Signal Processing, our health-related knowledge with respect to MRI, OCT, ultrasound and video-processing requires integration and connection to areas such as data-science, artificial intelligence and new sensor developments. Signal processing technology is a core driver of High-Tech System developments, not limited to the health applications where we have our focus. Requested positions: 5.
- Photonics and Wireless technology both use distinct parts of the electromagnetic spectrum. These technologies converge towards each other, both on component and system level,

providing new breakthroughs in sensing and communication. High-Tech System developments hinge on progress made in these two areas. However, the convergence requires fundamental obstacles to be overcome. Requested positions: 4.

- High-Tech systems with complex, tightly interconnected hardware and software (cyber-physical systems) are on the verge of what traditional design is able to handle. We need more complete ways of modeling ('multi-physics') and the most efficient ways of performing the associated computational work. We intend to develop this research within the context of one of our strengths, electro-mechanic systems for industrial automation, but the work will be relevant for High-Tech Systems development in general. Requested positions: 6.
- All of the above requires more efficient digital and analog electronics. For a long time, miniaturization provided increased efficiency, and as a result, there was little need to improve design methods. But now downsizing has come to an end, the current demands for speed, energy use and reliability must be met by improving designs. If we can't make it smaller, we need to make it smarter. The three technical universities jointly aim at positioning the Netherlands at the front of the developments needed to revitalize electronic design. Requested positions: 2.

4.3 Civil Engineering

Impact

Cities face enormous challenges because of global climate change. CO_2 emissions and the use of non-renewable resources need to be reduced drastically. The energy transition demands that in the Netherlands alone 6 million houses have to be retrofitted in order to reach the climate targets set by the European Union. To ensure safe living environments, strategies are required to mitigate the effects of increasing water levels, urban heat, and more frequent and increasingly violent storms.

The TU/e has built strong collaborations at national and international levels to jointly face these major challenges for the built environment. These collaborations include leading universities, research institutes and industrial partners, as well municipalities and public partners in the Brainport region. In addition, extensive collaborations have been established with Dutch universities of applied sciences, which include seamless learning pathways for students, partnerships in research projects, supervision of lecturers for obtaining a doctorate degree, and cross-institutional student teams.

Successful research applications in society include the realization of the first bridge (2017) and the construction of the first houses (expected in 2019) in the world by 3D concrete printing technology, and the building of a bio-based composite bridge (2016). An exceptional initiative by TU/e that is being realized in cooperation with public partners from the Brainport region, is the first truly 'smart' district in history. The 'Brainport Smart District', which contains 1500 houses, will be a unique living lab, in which all new and smart technologies are to be integrated in a renewable, social and attractive living district, with the ultimate goal to improve the quality of life of the inhabitants. The future inhabitants are closely involved in the development of 'their' district.

The strong basis in civil engineering and technology is what distinguishes the research and education at the TU/e Department of the Built Environment from similar departments worldwide. Because of the close ties with adjacent disciplines, fundamental civil engineering research is combined with research on renewable energy and smart city solutions, urban planning and development, mobility, user behavior and acceptance, and even allows for unique citizen science opportunities.

The cross-disciplinary approach results in highly successful projects funded by NWO and H2020 programs, participation in consortia addressing topics from the *Nationale Wetenschapsagenda* (NWA), such as 'Circular economy and resource efficiency'; 'Energy transition'; 'Materials made in Holland'; 'Smart liveable cities' and the *Topsectoren* 'High-tech Systems and Materials', 'Materials Science' and 'Sustainable Energy'. The department actively contributes to national developments, such as the *Renovatieversneller* in the national *Klimaatakkoord*, the BTIC, 4TU.Bouw, Taskforce *Bouwagenda*, the Transition team Circular Economy, amongst others.

Quality

Research groups in the civil engineering divisions have strong scientific reputations in the fields of theoretical derivation and modeling of multi-physical material behavior, the development of sustainable materials, shape and topology optimization, energy management and efficiency of structures, wind dynamics, and additive manufacturing (3D concrete printing). The academic impact and quality of these groups are demonstrated by an absolute top position (#1) for citations per paper and a #2 position for h-index in the 2019 QS World University Ranking and Field Weighted Citation Impact well above world average (1.67 period 2013-2017). Furthermore, high-quality experimental facilities are available in-house, including a large-scale 3D concrete printer in the Structures Laboratory, fully equipped Building

Physics Laboratories and the Atmospheric Boundary Layer Wind Tunnel with a 27-meter long test section.

Ambitions

Our investments in civil engineering significantly contribute to the TU/e profile as high-tech systems university of the Netherlands. In the coming decade, civil engineering disciplines will integrate and further develop technologies such as data science, artificial intelligence and new modelling techniques. We will contribute to the advancement of (new) building materials and structures with energy-efficient, circular and sustainable properties, which make structures lighter, stronger, more compact, and safer and the building processes more efficient and easier to work with. World-wide, we are scientifically at the forefront with these topics, and the *Sectorplan* enables us to reinforce this position. To further strengthen the technical basis and to integrate these topics adequately in the educational program of the department, we request *Sectorplan* funding for 7 tenure track positions. Continuing the department's successful recruitment strategy of the last years, we are confident that we will appoint at least 3 out of these positions to talented female scientists.

5 Preamble: TU/e Research and Education context

5.1 The first *Sectorplan Engineering*

In November 2017, the Ministry of Science and Education informed the Parliament of its decision to strengthen engineering disciplines through the format of the *Sectorplannen*, which had been used to successfully strengthen beta disciplines a decade ago. Accordingly, the Dutch engineering disciplines have described themselves in the *Sectorbeeld*[1] and the involved universities have formulated their plans to strengthen their disciplinary basis. This document describes the ambitions of Eindhoven University of Technology for its engineering disciplines.

5.2 The Dutch High-Tech Systems University

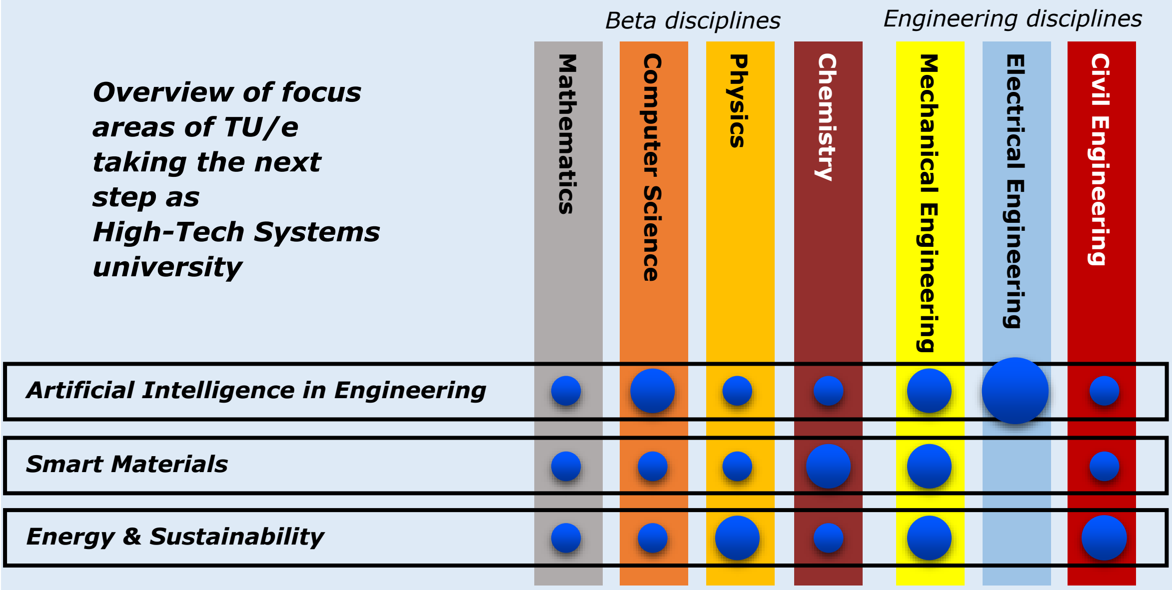
The core mission of TU/e is to advance knowledge and educate tomorrow's engineers & scientists. We work at the forefront of science & technology, with a central position in the high-tech systems knowledge and innovation ecosystem of Brainport. In this ecosystem some of the world's most advanced intelligent machines and electronic systems are developed and TU/e supplies the vast majority of newly graduated engineers to this ecosystem. In close collaboration with our public and private partners, we translate our basic research into meaningful solutions. TU/e subscribes to the need for sustainability and enables its students and scientists to become thought leaders in their field and to design and achieve technology for the benefit of humanity.

With the *Sectorplan* investments, TU/e will take the next step in the development of high-tech systems and sharpens its profile as the *High-Tech Systems University* of the Netherlands. To this end, TU/e will increase the capacity to educate engineers for society, invest in *Bèta* and *Engineering* disciplines, establish Cross-disciplinary Research Themes (CRT's) that connect these basic disciplines to solutions for society, and create partnerships that increase both the scientific and societal impact.

A common umbrella for these investments made by TU/e and the *Bèta* and *Engineering Sectorplannen* are three Cross-disciplinary Research Themes, which form the pillars of the TU/e as a *High-Tech Systems University*:

1) *Artificial Intelligence in Engineering*
2) *Smart Materials*
3) *Energy and sustainability*

The relation between the underlying disciplines and these themes is indicated in the scheme below and highlights the investments of the *Sectorplannen*, with the size of the circles corresponding to the number of positions on that cross-over point.



5.2.1 Artificial Intelligence in Engineering

Artificial intelligence will be the key element for next generations high-tech systems. These systems have to operate in a dynamic and changing environment, including situations and configurations that were not envisioned at design time. Engineers have to face major challenges to adapt the systems to

[1] "Een nieuw fundament: sectorbeeld voor de Technische Wetenschappen" (30 November 2018)

this environment. Physical processes are tightly interwoven with network/communication technology and high-level information and data processing. To take the next step, we have to take a broad perspective, go beyond artificial intelligence as data science, and develop digital, physical and chemical systems in unison. Using machine and deep learning, new technologies will integrate hard- and software and become increasingly 'intelligent', autonomous and interconnected. The design of such systems not only depends on optimization of the individual components, but also the quality of the interactions between these components and the systems environment. The resulting *systems approach* is a unique aspect of an engineering university. We integrate chemical and physical technology, functional materials, advanced sensing and actuation systems, related data science and intra- and inter-system communication aspects in a way that we can take the next step in high-tech systems. The importance of the systems approach and the development of artificial intelligence in engineering is evident for the industry in the Brainport region, and is also increasingly relevant to other areas of our society in which complex challenges arise such as the energy transition and health.

a. The Engineering *Sectorplan* positions within the theme of Artificial Intelligence in Engineering will lay the foundation of new developments for the next generation of intelligent (autonomous & connected) machines and other mechatronic/electronic systems by means of breakthroughs in the combined areas of hardware design, multi-physics modeling, model and data-based control techniques, imaging, signal-processing-algorithms and software implementation. Additionally, we will make progress within the area of optical and wireless communication so that these intelligent machines will improve communication speed and energy efficiency.
b. The Beta *Sectorplan* positions will focus on complementary disciplinary knowledge on data science, machine learning, complexity, quantum technology, fluid dynamics, and plasma technology.

5.2.2 Smart Materials

Smart Materials are materials that accurately and robustly meet pre-defined characteristics of a large and demanding variety. They require a profound understanding of the underlying properties and behavior during their production, processing, use and reuse. TU/e has a very strong position in (smart) materials through its research in the departments of chemical engineering and chemistry, mechanical engineering, applied physics and civil engineering. The Dutch industry relies on this kind of expertise in facing the materials challenges they encounter in the context of advanced responsive materials, biomaterials and circularity.

a. The part of the Engineering *Sectorplan* which relates to Smart Materials, is devoted to material development and production through multi-scale modeling, using experimental know-how over a wide range of scales from molecular scale up to system scale. We will focus on programmable changes of materials over time (the 4^{th} dimension), and on multi-material additive manufacturing methods, where physical and material properties of material systems are optimized for application in areas ranging from buildings to bio-tissues.
b. The Beta *Sectorplan* positions focus on new materials for photonics, spintronics, and on bio-inspired materials. Their shared intention is to achieve atomic level control of matter.

5.2.3 Energy & Sustainability

Energy & Sustainability is a theme that has a central position in the TU/e *Sectorplannen* for chemistry, physics, mechanical engineering and civil engineering. Major challenges relate to the efficient storage and reuse of stochastically available renewable energy sources and closing materials cycles. Metal fuels, heat storage and chemical conversion are the three pillars of the recently founded Institute for Renewable Energy Storage (IRES). TU/e's strong position in research in energy and sustainability is further enhanced by the presence of DIFFER on its campus. The research directions at TU/e have complementary counterparts in DIFFER, so the already existing intensive collaboration in the areas of fusion, chemical conversion, energy storage and porous media will be strengthened further by shared positions and joint programs. In addition, civil engineering structures such as wind turbines, solar farms in open field and solar panels on building roofs, are developed and optimized with respect to energy generation, storage, distribution and demand reduction.

a. The Engineering *Sectorplan* focuses on thermal energy storage, on wind and solar energy, and on energy storage in porous materials and metal powders. In porous media, energy can be stored and recovered using phase changes and chemical reactions. The use of Metal Fuels is a new and unique way to store sustainable energy in cheap, very compact, carbon-free recyclable form, i.e. metal powders especially for large-scale applications.
b. The Beta *Sectorplan* positions target chemical conversion (CO_2 towards fuels of higher thermal content), nuclear fusion and photovoltaics.

5.4 Partnerships

TU/e has entered a strategic partnership with Utrecht University (UU) and University Medical Center Utrecht (UMCU) to become leading in selected topics such as Energy and Health. The alliance has established and intensified joint research programs since 2011. In the framework of the *Sectorplannen,* many matching positions are identified by TU/e and UU in the fields of soft matter and complexity, light-matter interaction, climate physics, catalysis, high-dimensional systems, medical imaging and permeable media, colloids and complex fluids. With these positions, UU and TU/e aim to form the core of new alliance programs. Research Support Organizations & recruitment activities of both universities will be aligned to carry out the *Sectorplannen*. It is envisioned that Wageningen University will join to strengthen the alliance in the near future.

In the 4TU.federation (with TU Delft, UTwente and Wageningen University & Research) engineering disciplines cooperate in ten 4TU.Centres and research schools, which act as coordination mechanisms for specific topics. Under the umbrella of 'High-tech for a sustainable future' research programs are defined on topics such as health-oriented design, resilience engineering, internet of plants and soft robotics. In the EuroTech Universities Alliance (with DTU Copenhagen, TU München, EPFL Lausanne, Ecole Polytechnique Paris and Technion Israel), strengths are joined in collaborative PhD- and Postdoc programs and projects in areas such as data science, energy, photonics, health and mobility.

5.5 Cooperation with industry

TU/e aims to provide the world-class education and research that constitutes the life-line of the Brainport world-class high-tech ecosystem. More than 80% of the Dutch newly graduated engineers that start working in Brainport are educated at TU/e. TU/e is also world-leading in cooperation with industry as evident from the many professors-of-practice, the large number of collaborative scientific papers with industry and the high volume of 3rd-tier funding. Close to a quarter of private R&D in the Netherlands (~2 billion euro) is performed in Brainport. TU/e has created flagship initiatives with industrial and societal partners such as Philips, ASML, NXP, VDL, Océ, hospitals, and companies in the vast supply chains of the high-tech industry. In addition to this, TU/e has also many other strong collaborations such as with Shell, DSM, SABIC, AkzoNobel, Nouryon, BASF, Dow, FrieslandCampina.

5.6 A growing demand for education

In the last 8 years, TU/e's education has been revolutionized in order to attract students with a much wider orientation than just students with a beta mentality. This has been very successful, witnessed by the enormous increase in students, including the fraction of female students. The fraction of female students increased from 17 % before the BSC college (2011) to 27 % in 2018 for TU/e. This fraction even doubled for Mechanical and Electrical Engineering, from around 5% to 11 % and 9 %, respectively. The TU/e Bachelor College and TU/e Graduate School aim at educating the engineer(s) of the future: T-shaped engineers, who do not only control the discipline they are studying, but also learn to share and combine their disciplinary expertise with knowledge from other disciplines, including aspects within social sciences, humanities, economics, etc.

To accommodate the education of the engineer of the future, TU/e currently invests in teaching assistants or support staff and in educational innovations (development of different kinds of e-learning models and tools). This forms the basis of the TU/e Strategy 2030, which targets the next step in the change of the educational system using a variety of e-learning models including challenge-based learning, blended-learning, 21st century skills, new didactic forms, and ample room for students to develop their own learning path. The final phase of the BSc/MSc programs will involve individual face-to-face master-apprentice coaching in research topics related to the research of the staff. Yet, digitally supported teaching and testing and additional support by teaching assistants, will enable staff to also retain a proper balance between research and education.

TU/e has faced a sharp increase in student enrolment, and is expecting to grow from 7.300 in 2010 to 14.500 in 2022. Although more students are strongly needed, given the current and persisting large shortage of qualified engineers, the sudden growth necessitated TU/e to apply a *numerus fixus* to keep the student numbers under control for educational programs in Mechanical Engineering, Biomedical Engineering and Built Environment. The *Sectorplan* positions will allow us to disengage the *numerus fixus* for Mechanical Engineering and Biomedical Engineering, because we will again be able to handle the expected number of students, and we do not anticipate rapid further growth. For Built Environment, the student number prognosis is less clear, but we can increase the maximum number of students for the program, currently 275, by 25 students next year and depending on developments, the number may rise in the future, or the cap may be cancelled altogether. Electrical Engineering does not have a *numerus fixus.* Considering the need of Electrical Engineers in the Brainport region, influx trends and foreseen growth of staff, we expect to be able to maintain this situation.

5.7 Fostering research talent: recruitment and diversity

TU/e offers an open and collaborative research and education environment and emphasizes the independence of talented researchers in career development. This openness specifically pertains to diversity. TU/e is an international and inclusive community that strives for equal opportunities for students and staff from all nationalities, gender and cultural backgrounds. Our most formidable challenge in diversity is to increase the number of female students and staff, the more so since recruiting engineering talent is a fierce battle, and will remain that way while the shortage of engineers continues. For this reason, just a single initiative cannot achieve gender balance, and any action will need perseverance.

It is a major challenge to appoint this amount of new staff, among which more than 35% female. For that reason, TU/e's recruitment activities have been increased further. The current TU/e recruitment and diversity efforts are listed below:

- Chief Diversity Officer (prof. Eva Demerouti) has been appointed recently;
- Recruitment Support Organization @ TU/e has been installed recently;
- Sets of broadly defined gender-balanced positions in the (sub)disciplines have been published;
- Active gender-balanced search committees of young professors within (sub)disciplines have been installed to prepare long-lists of candidates using their own networks (status see below);
- Active recruitment and support by recruiters: direct approach of all long-listed candidates;
- Departmental boards **enforce a full 50-50 male-female balance** of short-listed candidates; this measure should result in the appointment of more than 35% female staff;
- To limit final drop-out of female candidates by dual career challenges, TU/e introduced the Dual Career Opportunity program for spouses which makes use of the Expat Spouses Initiative (ESI) in the Brainport area; the recruitment organization will also actively connect to companies like ASML, Philips, NXP, VDL and DAF;
- TU/e continues active outreach to secondary schools to attract more female BSc students for long-term gender balance. The general framework for these activities will be the Outreach-

program which is being composed in parallel to the Sectorplannen[2]. Outreach activities also extend to HBO, in helping them to make their education more attractive for female students;
- This june, the TU/e board introduced **the Irène Curie Fellowship program**, with the aim to boost the recruitment of female scientists further. Basic principles are:
    i. from June 1st, all new departmental vacancies will be opened in this program, exclusively open for female candidates for a period of at least 6 months;
    ii. after 6 months, the vacancy will be open to all genders, but following the strict rules mentioned above to reach a 50-50 male-female balance in finally selected candidates;

On top of all this, best practices will be shared with TUD, UT, RUG, WUR and UU. We also discussed with TUD, UT, RUG and WUR to share not-selected candidates, to see if they qualify for complementary positions at other universities. For a more elaborate overview of joint actions, see the separate alignment document (footnote 3 below).

5.8 National alignment

To organize and develop the *Sectorbeeld* and the *Sectorplannen*, the five universities involved in the Engineering *Sectorplan* organized a Board of Deans Meeting BoDeM (techniekoverleg). Supervised by the Board, the universities aligned the *focusgebieden*, the *zwaartepunten* and the positions proposed to strengthen the three disciplines. Many steps have already been taken and many will follow when the plans are implemented, described in the separate joint document[3]. That document also describes the status of refinement of the alignment in the three disciplines.

5.9 Reading

In the *Sectorbeeld*, the prioritized engineering disciplines (Mechanical Engineering, Electrical Engineering and Civil Engineering) have specified their area of research in a national context. The following chapters describe the *Sectorplan* proposals for strengthening each of these disciplines. The schematic on the next page provides an overview. Throughout the text, 'junior' level is equivalent to UD (assistant professor), and 'senior' level to (associate) professor.

[2] "Nationaal plan van aanpak HBO-Sector Techniek status en Outreach", May 2019, and "Nationaal plan Outreach", May 2019.
[3] "Joint Alignment Universities Sectorplan Techniek", May 2019.

Overview of TU/e proposals for disciplinary strengthening, showing relationship between *focusgebied* in the *Sectorbeeld* and TU/e *zwaartepunt*.

	Sectorbeeld **Subdiscipline & focusgebieden**	Sectorplan **Profilering**	TU/e Techniek **Subdiscipline & Zwaartepunten**
Mechanical Engineering	Thermo-fluids engineering * Low-carbon Energy Supplies Heat Transport and Storage	Multi-phase flows for low-carbon systems	1. Thermo Fluids Engineering *1a. (Multiphase) flows for low-carbon systems* *1b. Thermo-chemical conversion*
	Mechanical and Materials Engineering * Functional integration in material systems * Development and behavior of advanced Materials	Designer, Hybrid and Multifunctional Materials	2. Mechanical and Materials Engineering *2a. Designer and hybrid functional materials* *2b. Structure-property materials engineering*
	Systems and Control Engineering * Interactive, smart and autonomous Systems Interacting & Controlled Robot Systems	Interactive and Smart Autonomous Systems	3.Systems and Control Engineering *3a. Autonomous Systems* *3b. Dynamical Systems Design of High-tech systems*
Electrical Engineering	Communication and Signal Processing * Electromagnetic signal generation, acquisition and processing	Signal Processing for Health	1. Signal Processing and Imaging
	* Convergence Wireless and Photonics	Convergence Wireless & Photonics	2. Communication *2a. Integrated Photonics* *2b. Wireless Technology*
	Electronic Components, Circuits and Systems More-than-Moore Technologies * Design Methods for Electronic Systems	Design Methods for Electronics	3. Cyber-physical Systems *3a. Digital and Analog Electronics*
	Electrical Energy Conversion * Electromechanic Systems and Power Electronics Distributed Electrical Energy Supply	Design and Control of Electromechanical Systems	*3b. Data-Driven Intelligent Systems and Control* *3c. Electromechanical and Multiphysical Systems* *3d. Electrical Energy Systems & Smart Grids*
Civil Engineering	Fluid Mechanics for CiE structures		
	* Physics of CiE materials	Sustainable Civil Engineering Materials and Structures	1. Sustainable Civil Engineering Materials and Structures 2. Traditional building materials and systems
	* Mechanics of CiE structures	Wind loading on Civil Engineering structures	3. Wind loading on Civil Engineering structures
	Soil Mechanics		

Mechanical Engineering

6 Mechanical Engineering

The Mechanical Engineering discipline consists of 3 sub-disciplines, *Thermo-Fluids Engineering*, *Mechanical and Materials Engineering* and *Systems and Control Engineering*. The discipline finds its foundation in solid and fluid mechanics & dynamics, thermodynamics, materials science & engineering, systems & control technology, all with a firm basis in physics, chemistry and mathematics. The discipline includes overarching aspects of design and manufacturing. The sub-disciplines share modeling and analysis tools, equipment and measuring concepts, and fruitfully use each other's results.

6.1 Organization

At TU/e, the discipline of Mechanical Engineering is embedded in the Department of Mechanical Engineering, while all the activities in each of the sub-disciplines are organized in one of the three departmental divisions, each of them sharing research labs, infrastructure and technical staff, and each consisting of typically 20 fte scientific staff. The materials research of the department of Biomedical Engineering participates in the *Mechanical and Materials Engineering* sub-discipline. The disciplinary research within the three sub-disciplines/divisions is anchored very well within the three national research schools *JM Burgers Centre*, *Engineering Mechanics* and the *Dutch Institute of Systems and Control* respectively.

A strong connection exists with the *Topsectoren High-tech systems & Materials*, *Chemistry* and *Energy* and with many NWA routes, especially with *Energy Transition*, *Circular Economy*, *Materials*, *Smart Industry* and *Logistics & Transport*. The research in the divisions also connects perfectly with TU/e's main Cross-Disciplinary Research Themes on *High-Tech Systems, Smart Materials* and *Energy and Sustainability* (see figure in Preamble). The department of Mechanical Engineering is ranked 44th on the QS-ranking.

6.2 Zwaartepunten

UT, TU/e, RUG, WUR & TUD together identified several focus areas in each sub-discipline. One or two of them are strengthened in a complementary way at different universities along the lines of the *focusgebieden*, dependent on strengths. For TU/e, investments in artificial intelligence in engineering, smart materials and energy & sustainability are the basis to take the next step in high-tech systems and our profile as the high-tech systems university in the Netherlands. To do so, 2 *zwaartepunten* have been identified within each Mechanical Engineering sub-discipline, of which one is strengthened via the *Sectorplan*:

6.2.1 Sub-discipline 1: Thermo-Fluids Engineering

TU/e addresses the following 2 out of 3 research themes identified by TUD, UT and TU/e: (a) (Multiphase) flows for low-carbon systems and (b) Thermo-chemical conversion. For the 1st one strengthening is requested through this *Sectorplan*.

Zwaartepunt 1a: (Multiphase) flows for low-carbon systems

The energy transition is one of the major societal challenges humanity faces today. To support a society where sustainable energy is available anytime and anywhere, we must anticipate an unpredictable supply, so we are in urgent need of new storage materials and conversion technologies. TU/e therefore researches heat storage, conversion of gaseous and liquid future fuels (e.g. solar fuels), but as one of the few in the world, it also studies the very promising alternative of metal fuels. Metal powders burn (oxidize) easily, have a relatively large energy density, are abundant and their oxides can quite easily be converted back into metals, thus closing the cycle. The existing disciplines of combustion, complex reacting multiphase flows and energy technology therefore need extension by areas including reacting flows in dense metal-(oxide) dust systems, electrochemical reduction processes of e.g. dissolved metal-oxides, and complex flows in porous media for storage (subsurface storage, phase-change and thermo-chemical materials). Extension of our disciplinary knowledge on chemical reacting flow modeling using for instance reactive multiphase molecular dynamics and new diagnostic measurement techniques to visualize the internal porous and flow dynamics processes is needed. These themes play a central role in the new TU/e wide Institute on Renewable Energy Storage (IRES), which hosts the CRT on Renewable Energy. For the new area of metal fuels, we will appoint a senior researcher and a young staff member, while in the area of porous media flows we will allocate 2 junior positions.

Zwaartepunt 1b: Thermo-chemical conversion

TU/e develops experimentally validated models for flows in complex thermo-chemical equipment. Application areas are mainly related to conversion processes, like combustion in burners and engines, torrefaction of biomass, multiphase flows in (industrial) equipment such as heat-exchangers and compressors, separation, heating and cooling systems and flows in high-tech equipment. This local focus area is mature and will not be strengthened through the *Sectorplan*.

6.2.2 Sub-discipline 2: Mechanical and Materials Engineering

Within the field of Materials, the NWA-route *Materials made in Holland* defines 6 key research themes for the Netherlands. In agreement with TUD, UT and RUG, the sub-discipline 'Mechanical and Materials Engineering' addresses two of these NWA-themes in the *zwaartepunt* Designer & Hybrid Multifunctional Materials, and intends to strengthen this research through the *Sectorplan*. The other research activities in the sub-discipline constitute the *zwaartepunt* 'Structure and Property Materials Engineering', which will not be strengthened further.

Zwaartepunt 2a: Designer & hybrid multifunctional materials

TU/e targets materials which are of key importance for future engineering and societal developments (NWA Materials theme on *Designer Functional Metamaterials* and *Next-generation Engineering Materials*). *Designer materials* are enabling materials that change morphology and properties over time in a controlled manner. This constitutes the basis for the design of intelligent materials, materials with integrated actuators or sensors, meta-materials, programmable materials, etc. The class of *hybrid materials* are multi-materials with interfaces, combining engineering and natural materials (such as in soft robotics or hybrid implants/devices), as well as the interface between them. Integration of the two classes above leads to *multifunctional materials*, i.e. 4D materials and functionally integrated systems where the materials become the system. Of key importance is the manufacturing thereof, in which multi-material additive manufacturing takes a central position. These classes have been identified of key importance in a recent NWO-report and the NWA-route *Materials*. We will request strengthening this *zwaartepunt* with 1 senior position and 5 junior positions.

Zwaartepunt 2b: Structure-property materials engineering

The research on structure-property materials engineering builds on the knowledge and know-how to establish the relations required between the (small-scale) structure of materials and their engineering properties. The research is of key importance for the development, exploitation and lifetime of most engineering materials, and serves interest of many industrial partners relying on material performance in automotive, aerospace, energy, health and high-tech systems, but this mature area will not be strengthened via the *Sectorplan*.

6.2.3 Sub-discipline 3: Systems and Control Engineering

The sub-discipline 'Systems and Control Engineering' addresses two research *zwaartepunten*: (a) Autonomous Systems and (b) Dynamical Systems Design of High-tech systems. For the 1st one this *Sectorplan* will request strengthening.

Zwaartepunt 3a: Autonomous systems

Both industry and society foster high expectations of the future impact of autonomous systems. Examples are automated transportation systems (in line with NWA theme on Transport and Logistics), smart manufacturing systems (in line with the NWA theme on Smart Industry) and many more. In general, system autonomy has two benefits. On the one hand, it allows to take the human out of the loop to achieve increased performance and safety of engineering systems. On the other hand, it allows such systems to interact in real-world environments where interaction with humans is actually required. Both aspects support a step change in the pervasiveness of engineering systems in industry and society. The development of intelligent and interactive autonomous systems poses many challenges, on sensing, control, (world) modeling, human-machine interaction, system design, (big-)data management and algorithmic design. Key technologies for autonomous systems are investigated and developed at TU/e in close collaboration with the TU/e High-Tech Systems Center. The research is directed towards (i) modeling, sensing and control for complex autonomous systems, and (ii) autonomy in vehicular transportation systems. These subjects are proven strengths within the Mechanical Engineering Department of TU/e. This *zwaartepunt* will be strengthened with 4 young talented researchers.

Zwaartepunt 3b: Dynamical Systems Design of High-Tech Systems

The dynamical system design for high-tech systems is a core strength of the department of Mechanical Engineering of the TU/e and is firmly embedded in the Brainport high-tech region. This research theme is of key importance since society and industry pose increasingly stringent requirements on the functionality, performance, safety and agility of both high-tech products and processes, such as equipment for the semi-conductor industry, automotive systems, energy conversion, health applications, and medical robotics. But since the research infrastructure for this *zwaartepunt* is sufficiently mature due to TU/e internal investments, this *zwaartepunt* will not be strengthened through the *Sectorplan*.

6.3 Strengthening

As described in the previous section, TU/e proposes to strengthen the disciplinary basis of Mechanical Engineering along the chosen national focus area lines (see *Sectorbeeld*), in three *zwaartepunten*. Within Mechanical and Materials Engineering, they have been aligned on NWO/NWA-themes with the universities of Delft, Twente, Groningen and Wageningen (see the separate text provided by the joined universities involved in the technical disciplines).

The *zwaartepunten* will be detailed in the tables on the pages to follow:

- (1a) (Multiphase) flows for low-carbon systems: Table 6-a, page 20;
- (2a) Designer & hybrid multifunctional materials: Table 6-b, page 21;
- (3a) Autonomous systems: Table 6-c, page 22.

For a general overview, also refer to the schematic on page 13.

ME	Focus area Theme NWO/NWA	TUE	UT	TUD	RUG	WUR
TFE	Low Carbon Energy	- Thermo-chem conv. - Porous media flow - Future (metal) fuels	- Thermo-chem conv.	- Thermo-chem conv. - Hydromechanics - Multi-phase flow for low carbon systems - CO_2 capture - Aerodynamics - Aircraft propulsion	-	-
	Transport & storage of heat	-	- Heat storage, heat transfer & thermo, energy materials, advanced heat pumps, H2 storage	- Chem. reactor eng. - Heat pumps - Networks & phase transitions	-	-
M&M	*Functional Material systems* Designer functional (meta-materials) Soft- and bio-inspired materials Next-generation engineering materials	- 4D Multifunctional Materials	- Interactive material systems - Integrated sensor-designer materials	- Production technology - Energy- and resource-efficient production of materials - Medical Instruments & Medical Safety	-	-
		- Bio-inspired microsystems	-	- Biomechatronics	- Materials for biomedical applications	-
		- Multi-scale modelling of material systems	- Data-driven materials processing - Add. Manuf. of multi-material constructs	- Micro- and nano manufacturing - Smart & noise reducing materials	-	-
	Advanced materials Soft- and bio-inspired materials Next-generation engineering materials	-	-	- Materials with controlled degradability - Material interfaces for the Human body	- Multifunctional and hybrid supramolecular materials	-
		- Structure-property engineering - Material interfaces - Multi-material Add. Manuf.	- Computational design of structural materials - Polymer composites - Hybrid materials	- Hybrid Materials - Structural mechanics - Innovative composites - Materials for energy conversion	- Nanostructured materials - Multiscale modelling of multiphase materials	-
	Advanced materials (Sustainable materials)	-	- Recycling of elastomers & polymer composites	- Green materials, lifecycle, recycling and reuse an durability	-	-
S&C	Autonomous systems	- Design of High-Tech systems - Modeling, sensing & control of auton. systems - Autonomous vehicles	-	- Optimization based control - Data-driven modeling & control - Distributed space instruments	- Network control systems	- Autonomous greenhouse systems; - Adaptive, data driven food systems
	Interacting robot systems	-	- Smart supporting robots	- Human-machine syst. in space - human-robot interact - Auton. & self learn. control	- Instruments & robotic control	- Autonomous future farming (the 'green revolution'); - Adaptive, additive food assembly

Strengthened *zwaartepunten* in red, others in black. Note that this is not a complete list of the universities' research in Mechanical Engineering

Table 6-a

Eindhoven University of Technology, discipline of **Mechanical Engineering**

Subdiscipline & focusgebied	Profilering	Zwaartepunt
Thermo-fluids engineering		1. Thermo Fluids Engineering
* Low-carbon Energy Supplies	Multi-phase flows for low-carbon systems	*1a. (Multiphase) flows for low-carbon systems*

(Multiphase) Flows for Low-Carbon Systems

We propose to strengthen two related energy-themes: (1) metals as circular CO_2-neutral fuels, or more generally, multiphase flows in dense aerosols, and (2) flow in porous media. These two research areas of metal fuels and energy storage in porous media are main research topics in the newly founded *Institute for Renewable Energy Storage* (IRES) @ TU/e, which hosts the CRT on Renewable Energy and is complementary to the E-Refinery initiative at TU Delft. In IRES there is a collaboration with existing strong research lines on renewable fuels, combustion and multiphase flows. Within IRES the collaboration with the beta departments, DIFFER, CCER and UU will be enhanced. The research on porous media flows will be carried out in the Darcy lab and the work on metal fuels will be carried out in the Zero-Emission (ZE) lab, both part of the IRES lab. The ZE-lab is by 4TU-arrangement the only large-scale academic lab in the Netherlands where future fuels and future ultra-clean combustion concepts in engines are studied.

(1) Multiphase reactive flows in dense aerosols

In CO_2-neutral energy systems, energy is often stored in or extracted from dispersed reacting droplets, bubbles and particles. A relatively new example of this is metal fuels, a compact, CO_2-free recyclable large-scale energy carrier, a field unique in the Netherlands. The knowledge will lead to improved efficiency of these processes, such that they will become economically feasible.

(2) Flow in porous media

The investigation of complex (reactive) flows in porous media is essential for the understanding of physics related to energy storage phenomena, e.g. in subsurface Aquifer Thermal Energy Storage (ATES), but also in innovative heat batteries containing salt hydrates that undergo controlled phase-changes and/or hydration reactions.

Quality:

- **ERC**: 1 Starting Grant (Deen);
- **NWO VI**: 2 VENI (Oijen, Gaastra Nedea), 1 VIDI (Oijen);
- **NWO Gravitation:** contribution to NWO *Gravitation* program MCEC;
- **Overall output (2009-2018):** 524 journal papers;
- **Citations (2009-2018)**: 6770 (2.2 % in top 1% journals; 24 % in top 5% journals);
- **Awards:** 1 Simon Stevin Meester Award (de Goey)**,** 1 fellow of the Combustion Institute (de Goey);
- **Other marks of recognition:** Program leader STW Perspectief program Clean Combustion Concepts, contribution to ARC CBBC; Scientific Director 4TU Resilience Engineering Center; Board TKI New Gas, Advisory Board TKI Urban Energy, Program Board NWO-NAM DeepNL;
- **QANU evaluation**: maximum score (4 x 5) in last research assessment for Combustion Technology.

Impact:

- **EU projects**: Aether, Tango, POLKA, CleanSky 1, CleanSky2, CREATE;
- **Spin-off/start-up companies:** Fistuca, Progression Industry, SnoCom, HeatPower;
- **High-light:** TKI Energy program 'Compact Conversion & Storage' (CCO); TKI Energy projects Dope4Heat and Cap4Heat; NWO project Mat4Heat;
- **High-light**: With metal fuels a viable solution to long-term large-scale storage of sustainable energy is at reach. The first semi-industrial scale (100kW) system to produce steam is developed by a consortium of >10 partners, including student team SOLID (25 students) at innovation campus Metalot3C, of which prof. de Goey is founder & chair of the board. Further scale up (1MW) is planned on the industrial Metalot campus.
- **High-light**: Darcy Center for Porous Media. The combination of UU's famous fundamental research, Eindhoven's advanced technological background and UMC's medical expertise is used to advance porous media research in several areas, amongst which technology for geothermal energy and for CO_2 and hydrogen storage.

Education: Bachelor/Master program Mechanical Engineering (56966/60439), Master program Automotive Technology (60428) and Master program Sustainable Energy Technology (60443).

Staff: 9.4 fte permanent staff, proposed *Sectorplan* extension: 4 fte

Table 6-b

Eindhoven University of Technology, discipline of **Mechanical Engineering**

Subdiscipline & focusgebied	Profilering	Zwaartepunt
Mechanical and Materials Engineering * Functional integration in material systems * Development and behavior of advanced Materials	Designer, Hybrid and Multifunctional Materials	2. Mechanical and Materials Engineering *2a. Designer and hybrid functional materials*

Designer, Hybrid & Multifunctional Materials

We propose to strengthen two promising research lines to design and engineer future high-tech hybrid materials with specific integrated functionality:

(1) Function integration in material systems

Conventional materials are endowed with a morphology and microstructure that is designed and processed up-front, and which is not purposely altered thereafter. Allowing materials to change morphology and properties over time (the 4th dimension) in a controlled manner, enables materials to behave as actuators or sensors, or to be programmable. This development can be extended towards designing and creating materials, i.e. designer materials, which are functionally integrated systems, i.e. the material becomes the system. This development is stimulated by ongoing materials-driven miniaturization and function integration.

(2) Development, optimization and behavior of new advanced materials

Additive Manufacturing (AM) has huge potential and is widely advertised as the next industrial revolution, but there are still major hurdles related to the materials behavior under the AM processing regime in relation to the desired functionality. This specifically applies to hybrid materials, which are key for the next-generation engineering materials, but also for combining synthetic and natural materials in soft robotics, wearable devices and implants.

Quality:

Materials Technology (MaTe) is the cluster of research groups of Mechanical Engineering and Biomedical Engineering, collaborating on engineering (bio)materials, and the interfaces between them. MaTe has a very strong track record in theoretical fundamentals, computational tools and state-of-the-art experimental facilities for materials research across the scales. Quality indicators are:

- **ERC**: 2 Advanced Grant (Geers, den Toonder), 4 Starting Grants (Luttge, Van de Burgt, Hofman, Loerakker);
- **NWO VI**: 1 VICI (Bouten), 2 VIDI (Hofmann, Hoefnagels), 2 VENI (Hoefnagels, Dommelen);
- **NWO Gravitation:** 1 NWO *Gravitation* program (MDR);
- **Overall output (2009-2018):** 997 journal papers; 152 PhD theses;
- **Citations (2009-2018)**: 16000 (3,2% in top 1% journals; 27% in top 5% journals);
- **Awards:** 1 Aspasia Career development award**,** 1 EUROMECH-fellow, 1 IACM-fellow, 2 EAMBES-fellows, 1 elected member of AcademiaNet for Outstanding European Female Scientists and Scholars;
- **Other marks of recognition:** 1 President of the European Mechanics Society, 3 (associate) editors of international journals; 2 KHMW-members, 1 KNAW-member;
- **NWA**:1 member of the steering group NWA-materials.

Impact

- **Spin-offs**: OptiMal, Xeltis, Stentit, NC Biomatrix, Matereomics;
- **European projects**:NANOTHERM, SEED (EMJD), ProTechTion (EJD), LEE-BED, POSITION, ITN Tendon Therapy Train, ImaValve, LifeValve, TECAS (ITN), HybridHeart (FET-OPEN), iPSpine, STREPP F3, STREPP PEPTFLOW;
- **Industrial network**: all major Dutch companies in the field of materials, as well as several international companies;
- **Other high-lights**: maximum scores at the latest research assessment.

Education: Bachelor/Master program Mechanical Engineering (56966/60439), Bachelor/Master program Biomedical Engineering (56226/66226).

Staff: 14 fte permanent staff, proposed *Sectorplan* extension: 6 fte

Table 6-c

Eindhoven University of Technology, discipline of **Mechanical Engineering**

Subdiscipline & focusgebied	Profilering	Zwaartepunt
Systems and Control Engineering * Interactive, smart and autonomous Systems	Interactive and Smart Autonomous Systems	3.Systems and Control Engineering *3a. Autonomous Systems*

Interactive and Smart Autonomous Systems

We propose to strengthen our basis in autonomous systems research. The topic builds upon the current work in *zwaartepunt* 'Autonomous systems' for which key technologies are currently investigated and developed in close collaboration with the TU/e High-Tech Systems Center. Further development of autonomous systems requires breakthroughs in sensing, control, (world) modeling, human-machine interaction, hardware & software design, and (big) data management & algorithmic design. The research is directed towards the following topics:

(1) Modelling, sensing and control for autonomous systems

Key open challenges are: 1) How to combine first-principle modelling (existing expertise within TU/e) with data-based modelling techniques to obtain responsive models that support the decision-making of autonomous systems in real-world, uncertain environments, 2) How to develop sensing technology that provides autonomous systems with a real-time and accurate view of the world around them, and 3) How to develop control techniques for autonomous systems that make these systems 'intelligent' and that are applicable to complex, large-scale engineering problems.

(2) Autonomy in vehicular transportation systems

Domains within which system autonomy is highly promising are those of vehicular transportation systems, such urban & highway traffic systems, goods transportation systems in distribution centers and in harbors, etc.

Quality:

The research will be embedded within the *High-Tech Systems Centre* of TU/e (and the existing *Robotics, Automotive Technology* and *Dynamics and Control Technology* labs), in which researchers from this *zwaartepunt* will collaborate and focus on the theme of autonomous systems. TU/e has a very strong track record in systems theory, control technology and dynamical systems design. Research collaboration with the Departments of Electrical Engineering and of Mathematics and Computer Science will be further strengthened.

Quality indicators of this research team are:

- **ERC**: none;
- **NWO VI**: 1 VENI (Oomen), 2 VIDI (Oomen, Lefeber), 1 VICI (Heemels);
- **Overall output (2009-2018):** 1580 journal papers;
- **Citations (2009-2018)**: 17000 (1.4 % in top 1% journals; 19 % in top 5% journals);
- **Awards:** 1 Simon Stevin Meester award**,** 1 KIVI Academic Society Award, IEEE Control Systems Technology Award;
- **Other marks of recognition:** 3 IEEE fellows, TTW program iCave, rCPS, Flexcraft.

Impact

- **Leading** the High-Tech Systems Center & 3TU High-tech System Center;
- **EU projects:** 'oCPS', 'UCoCoS', 'Moby-Dic', 'WIDE', 'HYCON', HYCON2', 'iGame', 'Autopilot', 'Ropod', 'Tango', 'Polka', 'HYDRA';
- **Spin-off/start-up companies:** Preceyes, Microsure, Eindhoven Medical Robotics B.V., ZenMO, Sorama;
- **High-light**: Organization of the 2011 and 2016 Grand Cooperative Driving Challenges;
- **High-light**: Four times World Champion Robot Soccer (midsize-league) with TechUnited team in 2012, 2014, 2016 and 2018;
- **High-light**: In close cooperation with the EE department, "Stella" became World Champion in design of family cars with solar panels in 2013, 2015 and 2017. This initiative resulted in the start of a new company (Light-year) that recently received the Postcode Lottery award for innovative and green initiative.

Education: Bachelor/Master program Mechanical Engineering (56966/60439), Bachelor/Master program Automotive Technology (60428) and Master program Systems & Control (60359).

Staff: 17 fte permanent staff, proposed *Sectorplan* extension: 4 fte

6.4 Requested positions

In section 6.2 global indications of requested positions have been given. The table below specifies these positions in order of priority.

Table 6-d Requested Positions Discipline of Mechanical Engineering

Eindhoven University of Technology, discipline of **Mechanical Engineering**		
Priority	*Position*	
Versterkt zwaartepunt	*Position level*	
1	**Multi-materials Additive Manufacturing**	
Designer, Hybrid & Multifunctional Materials	Senior Experimental	
Additive Manufacturing is an emerging field of science and technology, whereby the processing of different materials in an integrated additive manufacturing route is largely unexplored. Fundamental challenges lie in integrating materials with distinct physical properties, mastering microstructures and controlling interface properties for multi-material combinations. *Related research*: Anderson, Cardinaels, Geers, Peters, Den Toonder, Remmers, Hofmann, De Boer. *Collaboration*: AMSYSTEMS Centre, Holst Centre, TU/e Control Systems Technology, UT.		
2	**Transport phenomena in dense reactive fuel clouds**	
(Multiphase) Flows for Low-Carbon Systems	Senior Theoretical	
Based on current expertise, new models will be developed for reacting flows in turbulent flows with dense clouds of particles, droplets and bubbles, e.g. for metal fuel combustion & metaloxide reduction back to metal dust. This new research field will deal with detailed particle-particle-fluid interactions in complex flows, e.g. creating propagating flame fronts due to mutual ignition and therefore needs a senior scientist. *Related research*: Van Oijen, De Goey, Deen, Tang, Roekaerts. *Collaboration*: DIFFER, IRES, TUD, ARC CBBC, TU/e-ST Multi-scale modelling of multiphase flows.		
3	**Multifunctional hybrid materials**	
Designer, Hybrid & Multifunctional Materials	Junior Theoretical	
Natural systems, where evolution has crafted unique base materials into hierarchical structures with dynamic mechanical functionalities, can serve as blueprint for materials that sense, respond and actuate their environment. This position concentrates on characterization of such systems to design novel materials with dynamic functions, or to integrate such functions into hybrid materials. *Related research*: Ito, Bouten, Loerakker, De Boer, Hofmann, Geers, Anderson, Hoefnagels, Den Toonder. *Collaboration*: TU/e-ICMS, UMCU-UU, Maastricht University, MDR gravitation program.		
4	**Autonomy in large-scale, networked systems**	
Interactive and Smart Autonomous Systems	Junior Theoretical	
Networked autonomous systems lead to challenges induced by the complexity and heterogeneity of the conglomerates of independent dynamical agents. A new approach is needed to analyze these systems and to design distributed and multi-level control systems communicating over (wireless) communication channels connecting them. Research in this field relies on expertise from control theory, graph theory, computer science, operations research, and optimization. *Related research*: Nijmeijer, Heemels, Reniers, Lefeber, Pogromsky, Van de Wouw. *Collaboration*: TU/e-W&I, TU/e-EE, TU/e-ICMS, RUG-ENTEG.		
5	**Design and engineering of multi-functional 4D materials**	
Designer, Hybrid & Multifunctional Materials	Junior Experimental	
The development of 4D responsive materials, metamaterials, materials with integrated actuators, or materials with programmable morphological changes hinges on their processing. This position focuses on the interdisciplinary design, processing and testing of such multifunctional materials. *Related research*: Anderson, Van de Burgt, Geers, Hoefnagels, Luttge, Den Toonder, Bouten, Ito, Hofmann, Loerakker. *Collaboration*: TU/e-ICMS, Leiden University.		

6	**Diagnostics in porous media**		
(Multiphase) Flows for Low-Carbon Systems		Junior Experimental	
Within the Darcy lab research focuses on heat transfer at the micro-scales and experimental validation (micro-PIV, 3D micro-PTV), including (evaporative) micro-channel cooling, AC-electro-osmosis and ferro-fluidics. The MRI diagnostic imaging techniques will be extended to XRD, CT, MRI. The new UD-TT will specialize on such imaging techniques. *Related research*: Smeulders, Rindt, Zondag. *Collaboration*: TU/e-UU-UMCU alliance, TU/e-AP TPM/WDY groups.			
7	**Data-based dynamical modelling and control**		
Interactive and Smart Autonomous Systems		Junior Experimental	
A challenge in autonomous systems is their interaction with other complex, both technological and societal, systems and humans. This challenge urges breakthroughs in responsiveness to uncertain environments and changing circumstances, to be expected from data-based modelling, control technology & online optimization, exploiting the availability of big data to make these systems intelligent. *Related research*: Van de Wouw, Oomen, Saccon, Fey, Antunes, Etman, Hofmann & Heemels *Collaboration*: TU/e-EE, TUD Delft Center for Systems and Control			
8	**Control for Autonomous and Cooperative Vehicles**		
Interactive and Smart Autonomous Systems		Junior Experimental	
The realization of autonomy in efficient and safe future transportation systems needs new strategies for control of individual vehicles, varying from Advanced Driver Assistance Systems to fully autonomous driving and cooperative driving. Significant synergy with state-of-the-art communication, automotive sensing developments and in-depth knowledge of vehicle dynamics is needed. Connection with sensor-technology and software architecture is essential. *Related research*: Nijmeijer, Zegelaar, Heemels, Hofman, Besselink, Van de Wouw. *Collaboration*: TU/e-EE, TU/e-W&I, TUD Delft Center for Systems and Control.			
9, 13	**Materials at the interface**		
Designer, Hybrid & Multifunctional Materials		Junior Experimental Junior Theoretical	
The design and engineering of materials that function at the interface with biological systems requires in depth understanding of the dynamic mechanical reciprocity at this interface. The corresponding complexity of the material design space necessitates a combination of experimental and computational modelling, leveraged by the advent of big data in materials engineering. *Related research*: Bouten, Ito, De Boer, Loerakker, Den Toonder, Luttge, Hoefnagels, Van de Burgt, Anderson. *Collaboration*: TU/e-ICMS, UMCU-UU, Maastricht University, MDR gravitation program.			
10	**Material microstructural design by Additive Manufacturing**		
Designer, Hybrid & Multifunctional Materials		Junior Experimental	
Unlike other methods, additive manufacturing has the ability to topologically tailor microstructures, thereby controlling engineering properties. Using state-of-the art experimental and computational techniques, AM processes can be analysed, optimized and designed at the level of microstructures, which will reveal an increased resolution towards smaller and smaller scales. *Related research*: Anderson, Cardianaels, Geers, Den Toonder, Hoefnagels, De Boer, Loerakker, Ito. *Collaboration:* TU Delft, AMSYSTEMS Centre, Brightland Materials Centre.			
11	**Computational flow modelling in porous media**		
(Multiphase) Flows for Low-Carbon Systems		Junior Theoretical	
Based on current complementary MD modeling, new models, e.g. based on DFT, Machine-Learning & Lattice Boltzmann will be developed for porous media flow, including reactions (at surfaces), mass/heat transport & phase changes. *Related research*: Smeulders, Zondag, Van Duijn, Gaastra-Nedea. *Collaboration*: TU/e-UU-UMCU alliance, DIFFER/CCER (Center for Computational Energy Research).			

12	**Distributed sensing, estimation and sensor fusion in combination with AI**		
Interactive and Smart Autonomous Systems		Junior Experimental	
Continuous developments towards plug-in, cost-efficient sensor technologies make the use of networks of distributed sensors feasible for numerous applications. Challenges to realize cost-effective and real-time applications, relate to minimizing the number of sensors required and realizing data compression by developing data fusion algorithms, pattern recognition methods and decision-making schemes tailored to each specific application. *Related research*: Lopez, Heemels, Oomen, Van de Molengraft, Van de Wouw. *Collaboration*: TU/e-EE, TU/e-W&I.			
13 see 9			
14	**Laser diagnostics in dense reactive fuel clouds**		
(Multiphase) Flows for Low-Carbon Systems		Junior Experimental	
Based on existing laser-based diagnostic expertise, new methods will be developed for flows with dense clouds of particles/bubbles/droplets. In the context of the *Sectorplannen*, TU/e-researchers discussed with TUD and UT to develop and build a joint 5D (3 space dimensions, time-dependent, spectrally resolved) set-up for ultra-fast imaging of complex flows. *Related research*: Dam, Deen, Homan. *Collaboration*: TU/e-TN Plasma Physics; ARC CBBC, TU/e-ST Inorganic Membranes & Membrane Reactors.			

6.5 Targets and Monitoring

Diversity

Mechanical Engineering fully supports the TU/e wide ambition to improve the gender balance in the department and has the ambition to appoint more than 35% of its new scientific staff to be female, which is regarded as a huge step forward. Gender balance has been a strategic focus point of Mechanical Engineering in the last 8 years. In 2010 the department had no female professors yet and typically 10% of the UD/UHD's were female, while in 2019 we have 3 female professors and the number of female UD/UHD's has increased to numbers around 20%. Note that Mechanical Engineering is traditionally a male occupation with a low fraction of females of typically 10% and a student outflow fraction of the same order in the Netherlands. Our success is related to a rather progressive recruitment strategy. International searches were performed using vacancy texts screened by members of the Women in Science network and supported by an external company to create long-lists of typically 50-80 candidates with roughly 20% of them being female candidates. All females were personally contacted by phone. This ended up with short-lists containing several female candidates. Yet in the end we were not able to appoint as many professors as desired because in a number of occasions, the female candidate withdrew, e.g. due to personal circumstances or a 2-body problem which was too difficult to solve. Part of the Biomedical Engineering Department participates in the *Sectorplan* of the Mechanical Engineering discipline. This part is more gender balanced (close to 50/50). The fact that this department participates with 14 out of 77 fte, explains the higher numbers for women in the tables below. Since 2018 each sub-discipline has its own recruitment team of 3-4 young full/associate professors who use their network to enhance the quantity, but also the quality of listed candidates. This is needed to be able to appoint a large number of new faculty related to the *Sectorplannen*. Our gender balance strategy will be further enhanced: department boards will demand a 50% fraction of women on the short lists, and we aim for more than 35% to be appointed finally, mainly due to considerations of quality and the persisting two-body problem. This is regarded as a huge step in view of the traditionally extremely low numbers.

The current inflow of 15% female Bachelor students within the discipline will be increased further by activity participating in the outreach to secondary schools in the environment to show how well females fit into the Mechanical Engineering profile. We will involve the female faculty in these outreach activities.

Knowledge Dissemination and Collaboration

Valorization and dissemination of knowledge to society takes place through many channels, being direct **knowledge transfer to industry** in many ways, through specific **software tools** for society developed within the research groups, through **hardware,** mainly being designed experimental set-ups and measurement systems and through **people**, mainly being the students delivered to society.

Dissemination of knowledge through teaching takes place through our participation in the Bachelor & Master programs on Mechanical Engineering, Biomedical Engineering and Automotive Technology, and the interdepartmental MSc programs Sustainable Energy Technology (4TU), Systems & Control, & Manufacturing Systems Engineering. Contributions to post-Master programs are mainly offered through our participation in the 3 main nationwide graduate schools: Engineering Mechanics (EM, solid mechanics), JM Burgers Centre (JMBC, fluid mechanics), Dutch Institute of Systems and Control (DISC, systems & control).

To maximise the societal impact of our research, the department focuses on:

- *Strategic Research Areas***:** Mechanical Engineering is actively involved in 3 TU/e Strategic Areas (SA) on Energy, Smart Mobility and Health. About 65% of the research of our PhD students is related to these areas. ME is the leading department of Smart Mobility & Energy;
- *4TU.Centres:* Energy, Research Data, Resilience, Fluid & Solid Mechanics, High-Tech Materials
- *Leading Technology Institutes:* Dutch Polymer Institute & Materials Innovation Institute;
- *Collaborations with industry***:** Mechanical Engineering collaborates with many industrial partners within Brainport and beyond. Strategic Partnerships are formed with parties like DSM, Philips and ASML. The department is also very active in Top Sectors Energy, Chemistry and High-Tech Systems and Materials. Very successful was the so-called 'Impuls' collaborative program in 2014-2018 in which 74 PhD students within Mechanical Engineering were jointly funded by industry and the TU/e board;
- *Valorisation by spin-offs and student teams:* extremely important is our research valorisation through successful student teams like Tech United, University Racing Eindhoven, Solar Team Eindhoven & Team SOLID. Mechanical Engineering primarily focuses on the spinning-out of patents and innovations by the creation of spin-offs & start-ups, with a target of 1-2 per year for each.

Other targets

With respect to other targets, we aim at consolidation or gradual growth, taking into account that the new junior staff will need the time until 2024 to reach a significant contribution.

With respect to the educational capacity and enrollement of students, TU/e aims to eliminate the numerus fixus in Mechanical Engineering and Biomedical Engineering on the basis of the sectorplan and other additional investments.

Table 6-e Staff targets – discipline of Mechanical Engineering

Eindhoven University of Technology, discipline of Mechanical Engineering	
	Target 2024
Permanent scientific staff (fte) Tenure trackers (fte) Post-docs (fte)	86 12 39
Women in permanent scientific staff (fte) Women in tenure trackers (fte) Women in post-doc positions (fte) Percentage of women appointed in sector plan positions	20 3 12 > 35 %

Table 6-f Quality and relevance indicators – discipline Mechanical Engineering

Eindhoven University of Technology, discipline of Mechanical Engineering		**Target 2024**
Quality	Competitive grants (ERC, NWO) *(last 2 years; in parentheses: all)*	
	Number of awards (Spinoza, Stevin, IEEE-level, etc.)	
	Number of papers *(FWCI; % in top 5% Journals)*	
	Other parameters of esteem	
Relevance	NWA grants in M€	
	Topsectoren grants in M€	0.7 M€/year
	Societal collaborations (narrative)	
	Number of patents	4/year
	Number of Start-ups / spin-offs	2/year of both
	Industrial collaborations in M€	11 M€/year
	Funding in 2nd and 3rd tier (M€)	2nd: 6 M€/year 3rd: 13 M€/year

Table 6-g Education targets – discipline Mechanical Engineering

Eindhoven University of Technology, discipline of Mechanical Engineering	
	Target 2024
Intake bachelor students	600
Percentage female	20 %
Intake master students	350
Percentage female	20%
Success rate BSc-diploma's	75%
Success rate MSc-diploma's	80%
Nr of PhD theses	40
% of PhD theses from women	25 %
Nr of Pdeng theses	3
% of PDeng theses from women	50%

Electrical Engineering

7 Electrical Engineering

The discipline of Electrical Engineering studies and teaches 'Communication & Signal Processing', 'Electronic Components, Circuits & Systems' and 'Electric Energy Conversion'. The three areas are strongly interconnected by their shared basis in *Electromagnetism* and *Systems and Control*. As a consequence, the discipline is firmly rooted in mathematics, computer science and physics, and contributes to fundamental research in these areas.

Synergy asks for complete coverage

Due to the common basis in the laws of electromagnetism (Maxwell's equations) and systems thinking, the discipline is characterized by a strong internal synergy. Electrical Engineering research results can often be applied to propel other Electrical Engineering research, thus creating a pace of change rarely seen in other disciplines. Developments in Electrical Engineering also catalyze developments in other disciplines. Because of the strong mutual synergy between the core elements of the discipline, the three Dutch universities of technology each aim to cover the basis of the discipline in an essentially complete way. This aligns well with the large societal demand for electro-technical knowledge: especially industry appreciates the disciplinary breadth at each site.

Strength by external focus

The three Dutch departments of Electrical Engineering differ in other aspects. In Eindhoven, the past twenty years have seen a remarkably large increase of the cooperation with industry, indirectly caused by a diminishing amount of direct government funding. This decrease incited the Eindhoven department to strengthen its focus on societal challenges: on the transition to renewable energy, on the networked society with freedom and rights of individuals, and on health. Associated funding opportunities are mainly provided by industry.

While such increased focus on cooperation with industry is beneficial for addressing short term challenges, it undermines the longer-term research and hence the basis for cooperation on the longer term. The department has been aware of the gradual impoverishing effect it is having on the more fundamental knowledge and research in the discipline. We are very pleased to get the opportunity to specifically and structurally strengthen our disciplinary basis and lengthen the time-horizon of our research, which will allow us to remain a strong partner for local and global industry.

7.1 Organization

At TU/e, the discipline of Electrical Engineering is studied in the Department of Electrical Engineering. The image processing research of the department of Biomedical Engineering participates in the Signal Processing sub-discipline. Research activities are primarily carried out in nine research groups which have a disciplinary focus, but in most of the research, staff from multiple groups cooperates in various settings. For the most visible applied research (in communication, cyber-physical systems and health), in which industry is usually also a partner, the department has set up *centers*, light-weight organizations which facilitate cooperation between groups and improve visibility.

The department is closely involved in *Topsectoren High-tech systems & Materials* and *Energy* and with many NWA routes, especially with *Energy Transition*, *The Quantum-Nano Revolution*, and *Smart Industry* and provides enabling technology for many others. The research in the department connects to all Cross-Disciplinary Research Themes (CRTs, see paragraph 5.2).

The department has a variety of labs, for example the largest electromagnetically shielded lab for wireless research in the Netherlands, a cleanroom with state-of-the-art photonic chip facilities, an anechoic EM-radiation lab, optical communications labs, a power electronics lab, a cyber-physical systems lab and a smart grids lab.

7.2 Zwaartepunten

In Eindhoven, research in Electrical Engineering has three *zwaartepunten*:

1. Signal Processing and Imaging
2. Communication
3. Cyber-Physical Systems

7.2.1 Zwaartepunt 1: Signal processing and imaging

In the area of signal processing, the orientation on society has led to strong positions in several, currently disjoint areas. In the medical field, the Eindhoven research is strong in patient monitoring and image analysis (including data engineering and artificial intelligence) to support medical diagnosis and the trend towards personalized healthcare. In communication-related signal processing, there is a strength related to wireless (e.g. 5G/6G) and optical communication. Both strengths are examples of a more general tendency to develop systems with large numbers of sensors: as sensing is becoming cheaper, new technical opportunities arise quickly, which depend on fast, often real-time, signal processing and imaging.

There is a strong potential for cross-fertilization across these historically distinct expertise domains. Accordingly we seek to unify our expertise in this area. It is also important to expand the health related research activities, since we are on the verge of creating technology that outperforms humans in diagnosis and treatment. We propose to appoint 5 additional staff members, one of which will be senior.

7.2.2 Zwaartepunt 2: Communication

The *zwaartepunt* 'Communication' covers our research in the transport, networking and processing of information. It notably addresses the booming needs in our increasingly networked society. Although radio-waves and light are both electromagnetic waves, wireless technology traditionally uses the radio spectrum up to 10-100 GHz, and optical communication uses infrared or visible light carried in glass fibers, with frequencies above 100 THz. At TU/e, the optical research has produced world-leading developments in optical signal processing chips (integrated photonics) in the Indium-Phosphide (InP) platform as well as powerful optical system and network platforms. Simultaneously, radio-spectrum technology is aggressively expanding into the mm-wave and THz regions for communication (5G and beyond) and sensing. Current demands for higher bandwidths, lower latency, larger networking flexibility and a smaller energy footprint can effectively be met by merging these technologies.

Efforts are already being made to connect the wireless and optical research domains. But to exploit our expertise and initiate globally relevant developments, we need a structural investment in basic research that stimulates this convergence. The *Sectorplan* would allow us to do so; we propose a staff extension of 4, which includes a senior position.

(Zwaartepunt 2a) Integrated Photonics

Two of these positions (1 senior) will be based in the area of photonic integration and systems for sensing, imaging and information transfer. The reinforcement will align with the National Agenda Photonics, a public private partnership which invests about M€ 250 into application-directed research in the Netherlands. Although application driven, the roadmap for this agenda identifies a range of fundamental topics to be addressed, for example to allow photonic circuitry and photonic system solutions integrated with electronics and to be used in wireless networks.

(Zwaartepunt 2b) Wireless Technology

The other two positions will have their roots in wireless technology and will address at system level and device level how optical technology could be used to create wireless networks for communication and sensing with capabilities beyond what is envisaged for 5G and at a drastically reduced energy consumption level. TU/e has a strong position in this area, covering topics such as on-chip antenna arrays, high capacity fiber transmission, mm-wave integrated transceivers, ultra-low power and low latency wireless circuits, optical indoor wireless, radio science and space instrumentation. In all these areas, speed and bandwidth requirements grow relentlessly, but the actual limiting factor is energy consumption. In complementing or replacing electronic functions, the use of optical technology promises energy reduction by orders of magnitude.

7.2.3 Zwaartepunt 3: Cyber-Physical Systems

Man creates complex systems, some of them machines such as chips-producing wafer-steppers, others rather systems of systems, such as the internet or the electricity grid. These so-called cyber-physical systems are systems of high complexity in which tightly interwoven software and hardware is directly interacting with physical processes and creates functionality which is significantly more than the sum of its parts. The research in cyber-physical systems covers a couple of closely related topics of the Electrical Engineering discipline: control and systems theory, the hardware and software for computing, and the digital and analog electronics which make this possible. All these aspects come together in the areas of high-tech equipment, electromechanical actuation, (wireless) sensing, (wireless) energy and information transfer, electrical energy supply and grids, and more. We propose to extend our staff with 8 interrelated positions, which includes one senior.

(Zwaartepunt 3a) Digital and Analog Electronics

At the core of cyber-physical systems are electronic integrated circuits (ICs). The miniaturization which was made possible by integrating circuits on chips, has been the basis for a number of far-reaching changes in modern society. ICs provided the computational power to design, analyze and handle complex systems. This process sustains itself, and before long, miniaturization brought about the necessary growth (Moore's law). But miniaturizing is becoming increasingly difficult, which causes a renewed need for better electronic design. The departments in Eindhoven, Delft and Twente therefore intend to undertake a joint effort to modernize design methods for analog and digital electronics. Two positions will be primarily devoted to this effort.

(Zwaartepunt 3b) Data-Driven Intelligent Systems and Control

Future engineering systems such as, smart energy systems, transportation systems and manufacturing systems, will be characterized by large-scale interconnections of dynamic components. They will be highly complex, multi-physics, heterogeneous and either physical connections or communication links will interconnect the different dynamic components into networked systems of systems. Ubiquitous sensing, actuation, communication, data handling and real-time computation will lead to systems that will have a complexity that goes far beyond the possibilities of our current automation systems.

This *zwaartepunt* involves development of sensor, imaging and actuator systems, the development and embedding of appropriate hardware and software into overarching automation systems for engineering systems of high complexity (so-called 'systems of systems'), including the development of learning methods for autonomous and adaptive controlled behavior, multi-agent control systems, and smart interaction with the environment (users). It includes concepts of 'correct-by-design' and 'provable guarantees of performance' of the interface between hardware and software.

We are developing the next generation of methods and tools for an ICT infrastructure that matches these future engineering systems of high complexity, as characterized above. It connects to the Industry 4.0 and Smart Industries agenda, the Internet of Things, as well as to the TU/e CRTs "Data-driven intelligent systems" and "Complex High-Tech Systems".

This *zwaartepunt* has a growing need to connect to developments in the *zwaartepunt* described below (3c), which takes a physical perspective on cyber-physical systems. We propose to accelerate research in this direction through 6 positions (combined with 3c), 2 of which will be senior.

(Zwaartepunt 3c) Electromechanical and Multi-physical Systems

Cyber-physical systems range from high-tech manufacturing systems and transportation systems to smart energy systems. In Eindhoven, we have a strong position in cyber-physical systems which center on electromechanical actuation, e.g. in an automotive context and in advanced semiconductor manufacturing equipment. To achieve the required performance, sensing systems, control systems and power electronics must be closely integrated, but the current state-of-the-art is not up to this task yet. The research is in need of more precise models, which include multiple physical modalities ('multi-physics'), of the tools to connect these models so that large systems can be simulated, and of new strategies to control these systems. These needs align with the developments in the *zwaartepunt* described above (3b). To provide for a basis which interrelates both, especially with respect to multi-physics modeling and control, artificial intelligence and model-based control, we propose to appoint the already mentioned 6 positions (combined with 3b).

(Zwaartepunt 3d) Electrical Energy Systems and Smart Grids

In a society which is moving towards a more central role of electrical energy (*electrification*), and towards a decentralized bi-directional network of generation and distribution of electrical energy (*distributed grid*), we are creating an electrical cyber-physical system with large proportions. At TU/e, we research the design, management and control of this network. That includes the power electronics, the sensor and communication networks which interface with the system, and the strategies to manage demand and consumption under a wide variety of operating conditions. TU/e has a sound strength in this area, which is why we choose not to strengthen it via *Sectorplan* investments.

7.3 Strengthening

The way in which the *zwaartepunten* will be strengthened, has been aligned with the technical universities (see paragraph 5.8 and the document referred to there). For TU/e, investments in artificial intelligence in engineering, smart materials and energy & sustainability are the basis to take the next step in high-tech systems and our profile as the high-tech systems university in the Netherlands. It resulted in the following choices (see also table next page).

TU/e proposes to strengthen the disciplinary basis of Electrical Engineering in four areas. These four areas will be detailed in the tables on the pages to follow:

- (1) "Signal processing and imaging": Table 7-a;
- (2a+2b) "Integrated Photonics" and "Wireless Technology": Table 7-b;
- (3a) "Digital and Analog Electronics": Table 7-c;
- (3b+3c) "Data-Driven Intelligent Systems & Control" and "Electromechanical & Multi-physical Systems": Table 7-d.

For a general overview, see the schematic on page 13.

EE	*Focusgebied*	TUE	TUD	UT	WUR
Communicatie en signaalverwerking	Convergentie radio en fotonica	- Integrated Photonics - Wireless Technology			
	Elektromagnetische signaal-opwekking, ontvangst en signaalbewerking	- Signal processing and imaging	- Communication and sensing - Health and wellbeing - Autonomous sensor systems	- Phased array antennas - Biomedical Signals and Systems - Image Processing	
Elektrische componenten, circuits, systemen	Ontwerpmethodieken voor elektronica en systemen	- Digital and Analog Electronics	- Unconventional electronics and computing systems - Health and wellbeing - Autonomous sensor systems - Safety and Security	- Analog and RF circuit design - Advanced computing systems	
	More than Moore-technologieën		- Health and wellbeing	- Lab/organ on chip - Vertical integration	
Elektrische Energieconversie	Gedistribueerde elektrische energievoorziening	- Electrical Energy Systems and Smart Grids	- Digital power systems - Micro-grid components and networks - High-Voltage Materials and Technologies		- Electrical Energy systems and Smart Grids: System and technology design for decentralized distribution systems
	Elektromechanische systemen en vermogenselektronica	- Data-Driven Intelligent Systems & Control - Electromechanical and Multi-physical Systems		- Robotics - Power electronics	

Strengthened *zwaartepunten* in red, others in black. Note that this is not a complete list of the universities' research in Electrical Engineering

Table 7-a

Eindhoven University of Technology, discipline of **Electrical Engineering**

Subdiscipline & focusgebied	Profilering	Zwaartepunt
Communication and Signal Processing * Electromagnetic signal generation, acquisition and processing	Signal Processing for Health	1. Signal Processing and Imaging

Signal Processing for Health

We propose to invest in expanding and unifying our expertise in health-related signal processing. It builds upon our *zwaartepunt* in 'Signal Processing and Imaging', which is embedded in the departments of Electrical Engineering and Biomedical Engineering.

To advance medical diagnostics to a level that approaches or surpasses human experts, technological advances are required along several intertwined lines:

a) exploitation of domain knowledge (e.g. models of pathophysiology and sensor characteristics),
b) combination of multiple sensor and imaging modalities along with patient-specific auxiliary information (e.g. age, BMI, genetic profile, etc.),
c) data-driven AI approaches capable of exploiting large and variegated data sets,
d) probabilistic signal and information processing frameworks that not only provide advice but also can quantify the confidence level of the advice along with an explanation that is interpretable to human experts, and
e) implementation approaches that permit real-time yet energy-efficient diagnosis, exploiting e.g. new architectures for computational hardware and novel mixed-signal or photonic integration approaches.

We seek to reinforce our core expertise in these areas. This expertise is of interest not only to the healthcare field but more broadly to that of complex signal and image processing systems. Accordingly it will contribute to and derive inspiration from signal processing advances in such areas as digital communication and autonomous driving. It will also help us to reinforce our ability to optimize complex signal and image processing systems across the entire acquisition/processing/interpretation chain. In addition, it provides the foundation for therapy strategies that exploit the plethora of sensory and imaging data for more targeted therapies.

Quality and Impact:

TU/e has a strong position in medical signal and image analysis, backed by an ideal regional configuration of university research, clinical research and medical equipment companies, and formalized in the e/MTIC (Eindhoven MedTech Innovation Center). The envisioned investments will strengthen this position. Indicators are:

- **ERC**: 3 Starting Grants (Mischi, De Greef, Lopata);
- **NWO VI**: 4 VENI (Rabotti, Lopata, Vullings, De Greef), 2 VIDI (Mischi, De Greef);
- **Overall output (2009-2018):** 2360 journal papers;
- **Citations (2009-2018)**: 43500 (3.7 % in top 1% journals; 16 % in top 5% journals);
- **Recognition:** IEEE Fellows (5), AES Fellow;
- **Supporting centers at TU/e**: Center for Care and Cure Technologies Eindhoven (C3Te) and Eindhoven MedTech Innovation Center (e/MTIC) (100+ PhD students);
- **Spin-off/Start-up companies**: SugarVita, MEDECS, CED, ViNotion, MEDSIM, CUDI, NEMO Healthcare, Hipermotion, LivAssured, Carelabs+;
- **Patents:** 100+ often jointly with industry;
- **EU projects**: Metabolic Syndrome (FP7 Flagship on Systems Medicine, 13.5 M€); ITN: ICareNet (coordinator), OpenGTN (coordinator), FBI, Musicare, Trabit; EWATCH (ITEA);
- **National project**: NWO-TTW: EWAM, BrainWave, HearScan, OSA+, LOCATE, OCT, SPICE, UMOSA; NWO Perspectief: ULTRA-X-TREME, Efficient Deep Learning; 4TU: Precision Medicine; PPS: NEUFEP, NeuroTrend, Perstim, MEDICAID, CoHear;
- **High-light**: Initiator e/MTIC, center with Brainport hospitals and Philips.

Education:

Students may specialize in this field in the Master of Electrical Engineering (60353, track on Care and Cure) and in the Master of Biomedical Engineering (66226) and Medical Engineering (60344).

Within both the Electrical Engineering and Biomedical Engineering educational programs, the new positions will strengthen education in data science, model-based signal processing, artificial intelligence and machine learning, and imaging modalities such as ultrasound and MRI.

Staff: 19 fte permanent staff, proposed *Sectorplan* extension: 5 fte

Table 7-b

Eindhoven University of Technology, discipline of **Electrical Engineering**

Subdiscipline & focusgebied	Profilering	Zwaartepunt
Communication and Signal Processing		2. Communication
* Convergence Wireless and Photonics	Convergence Wireless & Photonics	*2a. Integrated Photonics* *2b. Wireless Technology*

Convergence of Photonics and Wireless

We propose to address the gap between two *zwaartepunten* 'Integrated Photonics' and 'Wireless Communication'.

Bridging the gap between radio-frequency electronics and photonics will bring significant enhancements in communication speed, latency, network flexibility and energy consumption, both on component and on system level. Wireless technologies will profit from the speed, bandwidth, flexibility and the small energy footprint of photonic circuitry, and photonics will overcome existing limitations by complementing and interfacing with electronics. To have these technologies work together, the research will address:

1. Convergence on systems level, in which traditional optical and wireless system architectures are still separate worlds (e.g. radio-over-fiber).
2. Photonics and electronics must converge in a physical way, i.e. their separate production technologies (platforms) must be made to match, so that an intimate connection between circuits of both origins becomes possible.
3. Until now, the photonics research in Eindhoven has focused on communication applications, but circuitry will evolve to include an increasing amount of sensing and signal processing. The THz-range is specifically interesting for sensing, and the Indium-Phosphide platform offers promising prospects in this direction.

The profit to be gained will not only be visible in the area of communication and sensing, but it will catalyze parallel enhancements in computation hardware and signal processing. At the same time, these areas will contribute expertise about the most suitable technology for achieving electronic/photonic convergence.

Quality and Impact:

- **ERC**: 2 Advanced Grants (Smit, Koonen), 1 Starting Grant (Alvarado), 1 Proof-of-Concept (Koonen);
- **NWO VI**: 1 VICI (Williams), 2 VIDI (Alvarado, Maaskant);
- **Overall output (2009-2018):** 1225 + 1354 journal papers;
- **Citations (2009-2018)**: 8000 + 12000 (1.3/1.5 % in top 1% jrnls; 5/8 % in top 5% jrnls);
- **Zwaartekracht programs (2)**: Integrated Nanophotonics (2014-2023) and Networks (2014-2023);
- **Recognition:** IEEE Fellows (3), Fellow & Bell Labs, Lifetime achievement award (PIC intnl.);
- **Supporting centers at TU/e**: CWT/e, IPI, Photonic Integration Technology Center (PITC);
- **Spin-off/Start-up companies**: PhotonX Networks, MaxWaves, Effect Photonics, Bright Photonics, Genexis, Smart Photonics;
- **EU projects**: ITN: SILIKA (coordinator), CELTA (coordinator); H2020/FP7: PICS4ALL (coordinator), InPulse (coordinator) and OIP4NWO (coordinator), BlueSpace (coordinator), WIPE (coordinator), 5G-MOBIX, 5GPHOS, 5GSTEP-FWD, MetroHaul, PASSION, ELIOT, QAMELEON, WON; ENIAC/ECSEL: RF2THz, EAST, CORTIF, PANAMA;
- **National projects:** NWO-TTW: Photronics, FREEBEAM, INTEGRANT, MUSIC, FREEPOWER, 5G NXP-Partnership; PPS: SmartONE (KPN), 5GBasestation (NXP); 4TU: Plantenna;
- **High-light**: Government recognition of the economic importance of photonics has led to a large investment (M€ 250) in applied R&D, which will be used to extend the applied integrated photonics activities in Eindhoven;
- **High-light**: Conference chairs at European Conference on Integrated Optics, International Semiconductor Laser Conference, European Conference on Optical Communications, Wireless power Week; Chairman IEEE and URSI Benelux;

Education:

Students may specialize in this field in the Master of Electrical Engineering (60353). A special master track 'Connected World' is offered for students to specialize in wireless and/or photonics.

Developments in the field have recently triggered the initiative to design a specialized package of courses in Integrated Photonics and Wireless technologies, a so-called *on-line micro-master of 30 ECTS*, which is planned to be launched in 2020. The new positions will help to set-up these activities.

Staff: 24 fte permanent staff, proposed *Sectorplan* extension: 4 fte

Table 7-c

Eindhoven University of Technology, discipline of **Electrical Engineering**		
Subdiscipline & focusgebied	**Profilering**	**Zwaartepunt**
Electronic Components, Circuits and Systems * Design Methods for Electronic Systems	Design Methods for Electronics	3. Cyber-physical Systems *3a. Digital and Analog Electronics*

Design Methods for Electronics

We propose to enhance the design of analog and digital electronic circuits and systems. The topic builds upon the current strength in the *zwaartepunt* 'Digital and Analog Electronics'.

The three Dutch Electrical Engineering faculties have decided to join forces in developing better methods for the design of electronic circuits and systems, digital as well as analog. These methods will have to address:

1. Architectures for electronic systems at and beyond the performance limits of mainstream silicon and emerging technologies.
2. Circuits for electronic systems at and beyond the frequency and power dissipation limits of mainstream silicon and emerging technologies.

The advance of our expertise in these areas will be welcomed throughout the discipline. It will spin off to the development of cyber-physical systems and to photonic and RF circuitry, and in general to the development and embedding of appropriate hardware and software into overarching automation systems for engineering systems of high complexity (e.g. in industrial automation). We will develop the next generation of methods and tools for an ICT infrastructure which is able to match future engineering systems of high complexity.

Quality and Impact:

TU/e has a leading role in embedded systems, mm-wave and THz wireless circuit design as well as ultra-low power and battery-less mm-wave wireless sensing circuits. Extensive lab facilities for electronic circuit and systems research in the mm-wave and THz range are available.

- **ERC:** none;
- **NWO VI:** 1 VENI (Harpe), 1 VIDI (Harpe);
- **Overall output (2009-2018):** 930 journal papers;
- **Citations (2009-2018)**: 8750 (1.4 % in top 1% journals; 9 % in top 5% journals);
- **Recognition:** IEEE Fellows (2);
- **Supporting centers at TU/e**: High-Tech Systems Center (HTSC), Center for Wireless Technology Eindhoven (CWT/e);
- **Spin-off/Start-up companies**: Verintec Solutions, SMARBLE;
- **EU projects**: NeMeCo (ITN, coordinator), Par4CR (IAPP, coordinator), Phoenix (FET open, coordinator);
- **National projects:** NWO-TTW Perspectief: Efficient Deep Learning (coordinator), Zero; PR3 (REXUS challenge);
- **High-light**: A student team of EE led by a PhD student from the Electronic System group, successfully launched two experiments with the REXUS-25 rocket;
- **High-light**: Conference chair ISSCC;

Education:
Students attain a basis in this area in the Bachelor of Electrical Engineering (56953), and may specialize in the Master of Electrical Engineering (60353) or in the 4TU master Embedded systems (60331). The new appointed staff members focus area will also contribute to the new on-line micro-master on Integrated Photonics and Wireless technologies, to be launched in 2020.
The strengthening of the circuit design foundation will affect the Electrical Engineering bachelor courses related to this subject. Their redesign will be part of the new staff's task.

Staff: 19 fte permanent staff, proposed *Sectorplan* extension: 2 fte

Table 7-d

Eindhoven University of Technology, discipline of **Electrical Engineering**

Subdiscipline & focusgebied	Profilering	Zwaartepunt
Electrical Energy Conversion		3. Cyber-physical Systems
* Electromechanic Systems and Power Electronics	Design and Control of Electromechanical Systems	*3b. Data-Driven Intelligent Systems and Control* *3c. Electromechanical and Multiphysical Systems*

Design and Control of Electromechanical Systems

We propose to address the exponentially growing complexity of cyber-physical systems, in particular those involving electromechanical actuation. The topic builds upon the current strength in the *zwaartepunten* 'Electromechanical and Multi-physical Systems' and 'Data-Driven Intelligent Systems and Control'.

Fundamental multi-physical modeling (providing both qualitative and quantitative understanding of the multi-physical phenomena), systems' integration research and new experimental validation concepts will allow us to address the more general problem of designing cyber-physical systems. The modeling and experimental concepts will be integrated with the development of learning methods for autonomous and adaptive controlled behavior, for multi-agent control systems, for metrology, and for smart interaction with the environment (users). The unique research expertise in this area will provide new frontiers for the whole discipline, and it will specifically spin off to the development of automated systems of high complexity. We will develop the next generation of methods and tools for these areas. There is a particularly strong need to connect this research to the area of energy conversion and industrial automation: for high-performance electromechanical (electromagnetic, electrostatic, superconducting) actuators and for the design of power-electronic hardware. We propose to address specific research targets in these areas as well.

The broad and involving nature of designing cyber-physical systems implies that the necessary research will not be done within local or disciplinary boundaries. In particular, there is close cooperation with the Mechanical Engineering and Computer Science departments in the Autonomous Systems research program of the High-Tech Systems Center (HTSC).

Quality and Impact:

- **ERC**: 1 Advanced (Van den Hof), 1 Starting (Toth);
- **NWO VI**: 2 VENI (Lazar, Huiskamp);
- **Overall output (2009-2018):** 1130 journal papers;
- **Citations (2009-2018)**: 11500 (2.5 % in top 1% journals; 22 % in top 5% journals);
- **Recognition:** IEEE Fellow, IFAC Fellow, Honorary member Hungarian Academy of Sciences, Vice-President of IFAC, Vice-President of European Association of PE;
- **Supporting centers at TU/e**: High-Tech Systems Center (HTSC) and Center for Electrical Energy Technology and Systems (CEETSe);
- **Spin-off/Start-up companies**: Prodrive Technologies, UXsuite, Lightyear, Vital Fluid;
- **EU projects**: oCPS (ITN, coordinator), Autoprofit (FP7, coordinator), ASSTRA (ITN, coordinator), ADEPT (ITN, coordinator); ENIAC: DENECOR, DCC-G, E2COGAN, EPPL, EPT300, 3CCAR, THOR I, THOR II, ENLIGHT; ECSEL: AutoDrive, ModulED; Means4SG (ITN), M2M-grid (EraNet), UnitedGrid (H2020), SMAC (FP7);
- **National projects:** SES-BE (NWO Perspectief, coordinator); TKI: FlexStation, LowHarm, Unicorn, PQinControl; NWO-TTW: MAXMETA-XT, Robust CPS, Dispatch2, Tales, Agile, UHPA, EPECC, NAPAS, HSLM, HVAS; PPS: Intelligent Mechatronic Systems (ASML);
- **High-light**: In close cooperation with the ME department, we initiated the development of the STELLA solar family car by student teams, with winning positions in 2013, 2015, 2017. This initiative resulted in the start of a new company (Light-year) that recently received the Postcode Lottery award for innovative and green initiative.
- **High-light**: Conference chair at IEEE Powertech, Euro-Asian Pulsed Power Conference and the Conference on Linear Drives for Industrial Applications.

Education:
Students attain a basis in this area in the Bachelor of Electrical Engineering (56953) or Automotive Engineering (56953), and may specialize in the Master of Electrical Engineering (60353), or study the topic in the Systems & Control Master (60359) and in the Automotive Technology Master (60428). The strengthening of the foundation in this area will affect the Electrical Engineering bachelor courses related to this subject. Their redesign will be part of the new staff's task. More advanced topics, such as the non-linear theory for multi-scale modelling, computational aspects of multi-physics models or the control strategies involving these models, will become part of the master program.

Staff: 17 fte permanent staff, proposed *Sectorplan* extension: 6 fte

7.4 Requested positions

In section 7.2 global indications of requested positions have been given. The table below specifies these positions in order of priority.

Table 7-e Requested Positions Discipline of Electrical Engineering

Eindhoven University of Technology, discipline of **Electrical Engineering**			
Priority	*Position*		
Versterkt zwaartepunt		*Position level*	
1	**Advanced Electromagnetic and Electromechanic Systems Engineering**		
Design and Control of Electromechanical Systems		Senior Experimental	
Society increasingly relies on complex manufacturing, in an automated fashion and using robots. These processes all need high-power density electromechanical systems for fast, accurate and reliable handling of materials and objects. The position will address this need, and explore: • the design of electromechanical systems using high order models including multi-physics and multi-scale dynamics; • knowledge sustainability (reuse knowledge, avoid starting from scratch); • design of supporting software tools, possible AI, allowing reuse of models and providing visualization. *Related research*: Van den Hof, Weiland, Toth, Butler, Vermeulen, Steinbuch, Grilli (KIT), De Halle (UT), Krop, De Bruyn, Lomonova, Sergeant (UG), Dupre (UG). *Collaboration*: Mechanical Engineering (TU/e), High-Tech Systems Center (TU/e), Twente University, Karlsruhe Institute of Technology, ASML, SKF, Tecnotion, VDL, Prodrive Technologies, Bosch, SMAC (USA), Tenneco (Belgium), Hilti (Lichtenstein).			
2	**Complexity in Systems Analysis and Control**		
Design and Control of Electromechanical Systems		Senior Theoretical	
This position will develop modelling, control and optimization solutions that are able to cope with system complexity, through decentralized and distributed approaches, while guaranteeing reliable performance of the global system. This includes the development of learning methods for autonomous and adaptive controlled behavior. For application areas, the position will focus on the electrical engineering domain: multi-physics electromechanical and optical systems, energy networks and automated industrial production in Smart Industries applications. *Related research*: Van den Hof, Weiland, Lazar, Haesaert, Lomonova, Basten, Korporaal, Bergmans, Pemen. *Collaboration*: Mechanical Engineering (TU/e), High-Tech Systems Center (TU/e).			
3	**Photonic Integrated Circuits for Communications and Sensing**		
Convergence of Photonics and Wireless		Senior Experimental	
The position exploits the increasing levels of complexity achievable with (nano)photonic integrated circuit technology. Research will focus on the breakthroughs required to connect the technology to wireless systems including last meter communications, non-contact metrology and imaging. Functionality will leverage the speed, energy-efficiency and precision enabled by photonic circuits. *Related research*: Koonen, Linnartz, Fiore, Koopman, Kessels, Tafur-Monroy, Gomez-Rivaz. *Collaboration*: AMC Amsterdam, Radboud UMC, Twente University, VU Amsterdam.			
4	**Model-driven synthesis of digital circuits and systems**		
Design Methods for Electronics		Senior Experimental	
The position will research how to maximize performance, yield and life times of next generations of digital circuits, while minimizing power dissipation. We need to understand how transistor-level properties affect circuit and system behavior. Appropriate abstractions needed for integration of digital circuits in embedded architectures and electronic systems will be developed. Circuit and system synthesis techniques need to be co-designed. *Related research*: Pineda de Gyvez, Corporaal, Baltus, Goossens, Basten, Hamdioui, Benini. *Collaboration*: Center for Wireless Technologies (TU/e), Applied Physics (TU/e), Math & Computer Science (TU/e), IMEC, TU Delft, ETH Zürich.			

5	**Probabilistic Signal and Information Processing**	
Signal Processing for Health		Senior Theoretical
Signal and information processing are advancing from deterministic to probabilistic, from univariate to multivariate, and towards an integration of model-based and data-driven approaches. This senior position is meant to contribute to these advances. Main application contexts include biomedical diagnostics, digital communication, sensing, localization, and security with noisy data. Important prerequisites are the ability to build up a systems/solution perspective and to work across borderlines of disciplines (e.g. with implementation/hardware-oriented groups). *Related research*: Willems, Sommen, De Vries, Bergmans, Alvarado, Mischi, De With, Baltus, Basten. *Collaboration*: Center for Care and Cure Technologies (TU/e), Center for Wireless Technologies (TU/e), Eindhoven MedTech Innovation Center (TU/e), Biomedical Engineering (TU/e), Math & Computer Science (TU/e).		
6	**Optical domain signal processing in nano-cell wireless networks**	
Convergence of Photonics and Wireless		Junior Experimental
The position will develop theory and design for parallel signal processing and parallel computing with optical circuits, translating electronic functionality into the photonic domain. This will achieve significant reduction in latency and in computation power, which is essential in wireless applications and high-capacity optical networks. The primary inspiration will be the neuronal parallel processing in a brain. *Related research*: Williams, Koonen, Stabile, Exarchakos, Smolders, Tafur-Monroy. *Collaboration*: Institute for Photonic Integration (TU/e), Center for Wireless Technologies (TU/e), Math & Computer Science (TU/e).		
7	**Robust Multi-scale Fundamental Modeling in Multi-physics Phenomena**	
Design and Control of Electromechanical Systems		Junior Theoretical
Address top-complexity modeling problems of phenomena in which multiple physical effects appear and influence each other. These models must be sufficiently complex to describe the phenomena of interest and also still manageable to perform computations with. In high-tech electromagnetic detection and sensory applications, multi-physics aspects are starting to significantly impact the quality of measurements. Originally, these effects could be considered as noise on top of a strong electromagnetic signal, but by miniaturizing the sensors and by increasing their sensitivity, contributions from other physical phenomena can no longer be ignored. *Related research*: Van Beurden, Weiland, Lomonova, Luijten, Coene (TUD). *Collaboration*: High-Tech Systems Center (TU/e), AMOLF, Applied Physics (TU/e), ASML Research, TUD.		
8	**Integrated Circuit Design Quality Enhancement**	
Design Methods for Electronics		Junior Experimental
Architectural and circuit design of complex energy and information transfer and sensing systems involving emerging technologies as well as mainstream silicon ICs, as well as the methodologies needed to achieve such designs. This research will also contribute to the communication area and the convergence of wireless and photonics. *Related research*: Cantatore, Basten, Matters, Pineda, Harpe, Nauta (UT), Makinwa (TUD). *Collaboration*: Center for Wireless Technologies (TU/e), High-Tech Systems Center (TU/e), NXP, TNO.		
9	**Medium Voltage Power Electronics**	
Design and Control of Electromechanical Systems		Junior Experimental
Modeling, analysis and control of power grids, the behavior of which is dominated by the power electronics incorporated. The energy transition inevitably leads to these complicated grids, and modeling them is a root problem of most of the issues these grids face, ranging from component lifetime, supply-demand matching to operation stability, safety and long-term planning. *Related research*: Slootweg, Wijnands, Pemen, Serra, Lazar. *Collaboration*: Center for Electrical Energy Technology and Systems Eindhoven (TU/e), Enexis, Alliander, DNV-GL Flex Power Grid Laboratory, TNO-ECN, European Center for Power Electronics (ECPE).		

10	**Artificial Intelligence for Medical Imaging**		
Signal Processing for Health		Junior Theoretical	
In this position the focus will be on advancement of machine learning methodology, e.g. by incorporation of domain knowledge (self-supervised learning). Making AI suitable to process the full wealth of clinical data, in a way unattainable for the human brain, we aim to improve both the imaging process itself and the diagnosis and prognosis of disease. An important element of the research line will be the transparency and reliability of AI-based methods, critical for translation to clinical practice. Strong interaction with clinical and industrial experts will ensure relevance and validity of research questions. *Related research*: Bergmans, Florack, Petkovic, De With. *Collaboration*: Data Science Center Eindhoven (TU/e), Math & Computer Science (TU/e), TU/e-UU-UMC Utrecht Alliance, TU/e-Philips Alliance.			
11	**Optical Wireless Convergent Networks and Systems**		
Convergence of Photonics and Wireless		Junior Experimental	
Current and future wireless and mobile networks architectures, technologies and applications will need to integrate optical technology in order to meet bandwidth, speed, latency, energy and flexibility demands. The position will address this integration on an architectural, implementation and operational level. In particular it will research dynamic and real-time optimization of optical and wireless networks through artificial intelligence and data analytics. It will connect to network research outside the communication domain (e.g. power networks, sensing networks, biological neural networks). *Related research*: Heemstra de Groot, Tafur Monroy, Koonen, Niemegeers, Johannsen, Smolders, Willems, Bentum. *Collaboration*: Center for Wireless Technologies (TU/e), Institute for Photonic Integration (TU/e), Math & Computer Science (TU/e), NXP, KPN, Philips, Signify, TNO.			
12	**Artificial intelligence for state-estimation in systems medicine**		
Signal Processing for Health		Junior Theoretical	
In this position model-based signal processing will be developed, combining computer simulation models of the human physiological system, stochastic models of uncertainties and variation in the process, and (bio)sensor data, for application in systems medicine. Artificial Intelligence (AI) technology is applied for real-time learning and adaptation of the models, to accurately estimate the current state of the system and to predict its future trajectory. *Related research*: Kaymak, Van den Heuvel, Bergmans, Van den Hof. *Collaboration*: Data Science Center Eindhoven (TU/e), Math & Computer Science (TU/e), Industrial Engineering & Innovation Sciences (TU/e), Institute of Complex Molecular Systems (TU/e).			
13	**Sensor Systems – Processing, Control and Design**		
Design and Control of Electromechanical Systems		Junior Experimental	
Fueled by rapid cost decreases and functionality increases, sensors are rapidly pervading our society to permit truly intelligent systems (e.g. fully autonomous vehicles). To support this sensorization trend, we want to reinforce our fundamental expertise to derive meaningful and reliable information with low latency and computational effort from a large collection of multivariate and sometimes unreliable sensors, with a focus on novel sensors under study in our own department (e.g. optical, capacitive, THz). This will build upon combined expertise in sensor physics, signal processing/control and machine learning, supplemented by knowledge of key application domains. *Related research*: van den Hof, Williams, Baltus, Matters, Koonen, de With, Smolders, Mischi, Willems, Linnartz, de Vries. *Collaboration*: Institute for Photonic Integration (TU/e), Center for Wireless Technologies (TU/e), High-tech Systems Center (TU/e), Center for Care and Cure Technologies (TU/e), NXP, Signify, Philips, ASML, DAF, TomTom.			

<table>
<tr><td>14</td><td colspan="3">Technology for Magnetic Resonance Imaging</td></tr>
<tr><td colspan="2">Signal Processing for Health</td><td>Junior Experimental</td><td></td></tr>
<tr><td colspan="4">Current MRI procedures are expensive, time-consuming and often affected by motion. Developments in low- and high-field strength MRI provide avenues for, respectively, cheaper large-scale imaging and faster-microscopic imaging. This position (UD), will contribute to these developments from a systems perspective by integrating technology and knowledge from physics, photonics, electromagnetics and (high-power) electronics for next generation MRI. Important for advancing this field is working across the borderline of disciplines (e.g. in collaboration with software/application-oriented groups).
Related research: Paulides, Mischi, Aldenkamp, Raaijmakers, Tel.
Collaboration: Biomedical Engineering (TU/e), Applied Physics (TU/e), Industrial Engineering & Innovation Sciences (TU/e).</td></tr>
<tr><td>15</td><td colspan="3">Electronic Photonic Integration</td></tr>
<tr><td colspan="2">Convergence of Photonics and Wireless</td><td>Junior Experimental</td><td></td></tr>
<tr><td colspan="4">The position will develop new materials, device and circuit architectures to enable and exploit the intimate integration of photonic circuits with electronic circuits. The focus will be on wafer scale integration methods which are exploitable using regional know-how. Methods will focus on a paradigm shift in the trade-offs between energy and speed limitations in communications systems
Related research: Matters, Leenaerts, Koonen, Raz, Alvarado, Jiao, Van der Tol, Williams.
Collaboration: Institute for Photonic Integration (TU/e), electronic and photonics foundries engaged in state of the art industrially produced photonic (and electronic) integrated circuits.</td></tr>
<tr><td>16</td><td colspan="3">High-tech Multi-physics Systems & Control</td></tr>
<tr><td colspan="2">Design and Control of Electromechanical Systems</td><td>Junior Theoretical</td><td></td></tr>
<tr><td colspan="4">The modeling, control and analysis of high-tech systems requires an increasing coupling of different physical fields and different physical properties of processes in engineered systems. Electromechanical, thermal, thermo-fluidic, optical and chemical properties of materials need to be understood simultaneously and in terms of their mutual interaction. This position aims at providing novel tools to facilitate the integration and abstraction of multi-physics phenomena as they occur in the high-tech industry. Strong interaction with industrial partners in the high-tech sector will warrant the relevance of the research.
Related research: Van den Hof, Weiland, Butler, Vermeulen, Steinbuch, Krop, Toth, De Bruyn, Lomonova, Van Duivenbode, Van Beurden, Bergmans.
Collaboration: Mechanical Engineering (TU/e), High-Tech Systems Center (TU/e), ASML, SKF, Tecnotion, VDL, Prodrive Technologies, TNO, Thermo-Fisher, OCE-Canon, Philips.</td></tr>
<tr><td>17</td><td colspan="3">Combined Data-Driven and Physics-Based Modelling for Clinical Decision Support</td></tr>
<tr><td colspan="2">Signal Processing for Health</td><td>Junior Theoretical</td><td></td></tr>
<tr><td colspan="4">In this position the focus will be on the development and application of hybrid deterministic mathematical and probabilistic data-driven computer simulation models to predict outcome of medical interventions including advanced sensitivity analysis and uncertainty quantification. Parameters of interest for the clinic are either assessed patient-specific, using medical imaging and functional measurements, or patient-generic, using population-based data. In collaboration with medical device industry these activities will result in advanced integrated imaging and modelling platforms, that can provide clinicians with new (not directly measurable) clinical quantities that aid in diagnosis, monitoring, and decision making are developed and.
Related research: Mischi, Van den Heuvel, Hilbers.
Collaboration: Eindhoven MedTech Innovation Center (TU/e).</td></tr>
<tr><td colspan="3"></td><td></td></tr>
</table>

7.5 Targets and Monitoring

Diversity & Collaboration

The targets of our *Sectorplan* investment are specified in Tables 7-f, 7-g and 7-h. For our diversity targets, we refer to the university policy on enlarging cultural, gender and age diversity (see paragraph 5.7). With respect to gender balance, we face a situation similar to Mechanical Engineering and our response is similar too. Our open science policy is also in line with the university policy. We disseminate our knowledge to our students and to industry. The number of Electrical Engineering students has increased by about 200% since 2010, and although this comes close to the limit our staff can handle, we have been able to avoid a *numerus fixus*. Still, societal demand for Electrical Engineering graduates is larger than what we provide. If the number of students will increase further, we will try to accommodate them. The *Sectorplan* investments will help us to do so.

With respect to dissemination of knowledge to industry, see the introduction to this chapter. The department has a large network of industrial contacts which take our research results to a higher, more applied level. We have established a set of so-called ‘centers’, which have the explicit task to interface with industry in order to facilitate knowledge transfer. Our success in acquiring 3rd tier funding is an indication of the quality of this process. A stronger disciplinary basis will allow us to remain the solid partner we currently are, also for the longer term.

Although our collaboration is primarily with industry, a relevant part of our research is together with other partners, mainly in a large number of 2nd tier and 3rd tier funded contracts. For as far as relevant, these collaborations have been specified in Tables 7-a to 7-d, and in the positions listed in Table 7-e.

Other targets

With respect to other targets, we aim at consolidation or gradual growth.

Table 7-f Staff targets – discipline of Electrical Engineering

Eindhoven University of Technology, discipline of Electrical Engineering	
	Target 2024
Permanent scientific staff (fte)	115
Tenure trackers (fte)	23
Post-docs (fte)	39
Women in permanent scientific staff (fte)	14
Women in tenure trackers (fte)	15
Women in post-doc positions (fte)	11
Percentage of women appointed in sector plan positions	≥35%

Table 7-g Quality and relevance indicators – discipline Electrical Engineering

	Eindhoven University of Technology, discipline of Electrical Engineering	**Target 2024**
Quality	Competitive grants (ERC, NWO) *(last 2 years; in parentheses: all)*	
Quality	Number of awards (Spinoza, Stevin, IEEE-level, etc.)	
Quality	Number of papers *(FWCI; % in top 5% Journals)*	
Quality	Other parameters of esteem	
Relevance	NWA grants in M€	
Relevance	*Topsectoren* grants in M€	2.5 M€ / year
Relevance	Societal collaborations (narrative)	
Relevance	Number of patents	13/year
Relevance	Number of Start-ups / spin-offs	3 or 4 /year
Relevance	Industrial collaborations in M€	15 M€/year
Relevance	Funding in 2nd and 3rd tier (M€)	2nd: 8 M€ /year 3rd: 22 M€/year

Table 7-h Education targets – discipline Electrical Engineering

Eindhoven University of Technology, discipline of Electrical Engineering	
	Target 2024
Intake bachelor students	400
Percentage female	20%
Intake master students	360
Percentage female	25%
Success rate BSc-diploma's	70%
Success rate MSc-diploma's	80%
Nr of PhD theses	55
% of PhD theses from women	25%
Nr of Pdeng theses	10
% of PDeng theses from women	40%

Civil Engineering

8 Civil Engineering

Together with the universities of Delft, Twente and Groningen, the discipline of Civil Engineering in the Netherlands was described in the *Sectorbeeld* along 4 sub-disciplines, which were also identified as *focusgebieden*: *Fluid Mechanics for Civil Engineering Structures*, *Physics of Civil Engineering Materials*, *Mechanics of Civil Engineering Structures*, and *Soil Mechanics*.

Discipline development

Traditionally, the focus of civil engineering research at TU/e is on structural design processes, on the mechanical and physical behavior of conventional building materials and systems, and on analytical and numerical analyses of materials and structures for (building) engineering applications. The research approach has always been holistic, combining disciplinary research with interdisciplinary collaboration. The strong basis in engineering and technology is what distinguishes the research and education at the TU/e Department of the Built Environment from similar departments worldwide.

Since the past ten years, the disciplinary focus in Eindhoven has been more and more aimed towards the fundamental study of mechanical and physical behavior of materials and structures, which has reinforced the technical basis of research and education. Furthermore, societal challenges as a result of global climate change have led to a strategic shift in research focus to include aspects of sustainability, circularity and safety of civil engineering materials and structures.

8.1 Organization

At TU/e, the 2nd and the 3rd sub-discipline (*physical aspects of civil engineering materials* and *mechanical aspects of civil engineering structures*) are studied and taught at the divisions Structural Design and Building Physics of the Department of the Built Environment. Both civil engineering divisions closely work together in research and education with the other divisions from the department, which together cover the complete range of disciplines related to science and engineering in the built environment, from architectural design and engineering to smart city technologies, and from urban planning and transportation to urban development and real estate.

Research groups in the civil engineering divisions have strong scientific reputations in the fields of theoretical derivation and modeling of multi-physical material behavior, the development of sustainable materials, shape and topology optimization, energy management and efficiency of structures, wind dynamics, and additive manufacturing. The academic impact and quality of these groups are demonstrated by an absolute top position in their field (#1) for citations per paper and a #2 position for h-index in the 2019 QS World University Ranking and Field Weighted Citation Impact well above world average (1.67 period 2013-2017). During the most recent Research Assessment, the international peer review committee awarded the research groups the highest scores on Research Quality and Societal Relevance (SEP score 1; world leading).

High-quality experimental facilities are available in the Structures Laboratory, the Building Physics Laboratories and the Atmospheric Boundary Layer Wind Tunnel. Both research groups have built strong co-operations with industry as well as with highly ranked international universities.

The civil engineering research topics are associated with the university's strategic cross-disciplinary research themes (CRTs) 'Smart Materials & Processes', 'Complex High-tech Systems' and 'Renewable Energy'. National alignment and coordination with regards to research, education and organizational matters take place in 4TU.Bouw and OCIB, in which the TU/e actively participates.

Increasing diversity of staff has been key part of the departmental board's recruitment strategy in the past years, demonstrated by the fact that since 2015 40% of newly recruited scientific staff within the discipline of civil engineering was female. The same percentage applies to the diversity in nationality of recruited staff, i.e., 40% is non-Dutch.

8.2 Zwaartepunten

In Eindhoven, the discipline has the following *zwaartepunten* (see the *Sectorbeeld* for more details):

1. Sustainable Civil Engineering materials and structures
2. Wind loading on Civil Engineering structures
3. Traditional building materials and systems

The requested *Sectorplan* positions aim at reinforcing research into the first two areas. In preparation of this proposal, it was mutually agreed that at the TU/e the focus of research will be on multi-physics, physical properties and sustainability, whereas the TU Delft will focus on multiscale aspects, mechanical properties and durability. It was also agreed that in relation to wind impact, UTwente will focus on wind impact in the coastal area, especially on the mechanics of coastal defenses consisting of natural, loose materials (sand), whereas the TU/e focus will be on wind impact on offshore and land-based structures, wind turbines, solar farms and vibrations in structures.

The faculty has a strong preference to realize the personnel expansion with young tenure track positions, in order to better balance the current staffing that includes a relatively large number of Full Professors, of which several with an appointment wholly or partly financed by industry.

8.2.1 Zwaartepunt 1: Sustainable Civil Engineering materials and structures

Building activities are the greatest global user of materials and energy: they relate to about 40% of the total energy consumption in the world and 50% of the material usage. For the reduction of greenhouse gas emissions and to mitigate global warming, the raw material consumption and the energy consumed in building processes need to be decreased drastically. This has induced a growing interest to develop a holistic view on the environmental impact of material production, energy consumption during production, transport and use, and the durability and service life of civil engineering structures. Accordingly, novel sustainable and circular building materials must be developed, the embodied energy of existing building materials should be decreased, and structures must optimally facilitate the generation, storage and distribution of energy.

In relation to this aspect, 3D-printing is a promising development that requires further scientific research (TRL 3-6). In comparison to traditional building processes, 3D-printing has the advantage that the structure is easy to customize with an enormous flexibility in shape. However, what is even more important from the perspective of sustainability, is that less resources are required and product waste and manufacturing and storage costs are reduced, because only material that is directly required for the structure is being printed. In addition, the physical labor effort from the manufacturing workers is kept low, thereby improving their health condition and efficiency during construction. Driven by groundbreaking research activities by the TU/e, the first proto-types of bridges, houses and structural components have recently been successfully 3D printed. However, little is still known about the influence of the process parameters and conditions on the structural performance during the process itself and in the subsequent serviceability phase. We look forward to further investigating these topics, in order to advance the knowledge about the optimization of 3D-printed structures in terms of its weight distribution and material use, and enable the development of novel, energy-friendly building materials suitable for 3D-printing, and the 3D-printing of structures with tailor-made (thermal, hygral, electrical) properties.

8.2.2 Zwaartepunt 2: Wind loading on Civil Engineering structures

Over 70% of damage and deaths caused by nature are due to extreme wind conditions, which makes wind the most destructive natural phenomenon. A thorough investigation of wind effects on civil engineering structures is of utmost importance in order to warrant the safety of these structures at minimal building and maintenance costs. Although wind effects on structures have been analyzed for decades, various aspects still require fundamental and ground-breaking research. For example, there is increasing evidence that intense wind speeds and heavy wind damage are often not related to the well-studied synoptic phenomena on which research has focused on in the past half century, but rather to extreme events such as thunderstorms and downbursts. Furthermore, the tendency in construction towards higher, longer and more slender bridges, towers and buildings, asks for a detailed understanding of the complex interactions between the wind loading and these flexible structures. In addition, the recent development of wind and solar farms introduces a new class of vulnerable structures that frequently experience unforeseen damage due to wind loading.

8.2.3 Zwaartepunt 3: Traditional building materials and systems

The more traditional building materials, such as steel, aluminum, timber and masonry, are researched in terms of their material properties, mechanical behavior, and application in structural design. Knowledge of fracture mechanics, damage and plasticity theories is required for developing analytical, numerical and experimental tools that serve for the validation of existing and new design rules and models. In addition, computational models and simulations are carried out for optimizing design and operation of buildings and systems in terms of energy use and indoor environmental quality. These models include underlying theories from different disciplines, such as physics, mathematics, human behavioral, environmental and computational science, as well as civil, mechanical and electrical engineering. TU/e has a solid position in this area, which we choose not to strengthen via *Sectorplan* investments.

8.3 Strengthening and requested positions

As described in the previous section, TU/e proposes to strengthen the disciplinary basis of Civil Engineering in two *zwaartepunten*. These have been aligned with the other Dutch universities involved in the discipline (see paragraph 5.8 and the document referred to there). For TU/e, investments in artificial intelligence in engineering, smart materials and energy & sustainability are the basis to take the next step in high-tech systems and our profile as the high-tech systems university in the Netherlands. The Civil Engineering investments contribute to that profile. They have been introduced above and will be detailed in the tables on the pages to follow:

- (1) "Sustainable Civil Engineering materials and structures": Table 8-a;
- (2) "Wind loading on Civil Engineering structures": Table 8-b.

For a general overview, see the schematic on page 13.

Civil Engineering	TUE	UT	TUD	RUG	WUR
Fluid mechanics for CiE structures	-	Fluid dynamics and sediment transport in human-influenced marine, inland and urban water systems. *Focus on computational methods to reach long and large scales so that e,g. climate changes can be evaluated.*	*-small-scale and multi-scale physics-based hydraulic processes* *-large-scale urban systems with dynamic interactions (rainfall models)*	-	*- Fluid dynamics of mixed cohesive-noncohesive particulate suspensions in rivers, estuaries and urban systems* *- Hydraulics of small scale, high loaded pressurized systems for small-urban conglomerates*
	-	Computational Methods in Fluid Dynamics for Nature Based Solutions *Focus on coastal applications explicitly including all climate zones (e.g. mangroves)*		-	*- Feedback mechanisms between turbulent flow, sediment transport and bed morphological change under the influence of vegetation*
Physics of CiE materials	*-Multi-physics modelling and testing of sustainable and circular materials* *-Optimization of 3D printed structures and 3D printing processes* *-Energy generation and storage in structures*	-	*-multi-scale mechanical modelling for durability characterization and novel materials* *-additive manufacturing - material scale*	-	-
	-Mechanical behavior and application of traditional building materials (steel, aluminum, timber, masonry)	-		-	-
Mechanics of CiE structures	*-Modelling and testing of wind impact on offshore and land-based structures*	*Numerical methods and modelling of wind impact in coastal area, focus on mechanics of sediment based coastal infrastructure*	*-dynamics of structures and structural health monitoring* *-multi-scale structural mechanics and mechanics of structural interfaces*	-	-
Soil Mechanics	-	Soil Infrastructure Interaction *Focus on construction works, predictive maintenance, and on the particular domain of utilities*	*-composition, heterogeneity and mechanical behaviour of deltaic soils* *-soil/water/structure interaction*	-	-

Strengthened *zwaartepunten* in red, others in black. Note that this is not a complete list of the universities' research in Civil Engineering

Table 8-a

Eindhoven University of Technology, discipline of **Civil Engineering**

Subdiscipline & focusgebied	Profilering	Zwaartepunt
* Physics of CiE materials	Sustainable Civil Engineering Materials and Structures	1. Sustainable Civil Engineering Materials and Structures

Sustainable Civil Engineering Materials and Structures

There is an urgent need to replace traditional building materials with energy-efficient, circular and sustainable materials, which make structures lighter, stronger, more compact, and safer and the building processes more efficient and more work-friendly.

To achieve this goal, i) the mechanical properties (i.e., stiffness, strength, deformation capacity) and physical properties (i.e., conductivity of moisture and temperature, resistance to harmful chemical reactions) of these materials must be adequate, ii) a high processability and structural feasibility in the construction phase must be realized, and iii) complex interactions between the light structure and the loading, as, for example, is the case with wind turbines, must be fathomed and optimized.

We propose to strengthen research and expertise on sustainable materials and structures, specifically on the aspects related to the analysis and prediction of mechanical behavior of civil engineering materials by means of coupled multi-physics models and the development of numerical shape and topology optimization tools for the 3D printing of civil engineering structures with complex shapes. Additionally, we focus research on circularity of cementitious materials and the development of new solutions for energy generation, storage and distribution in civil engineering structures.

Because of the strong interdisciplinary relations and the established collaborations with industry, the TU/e has a unique position to perform research and validate results which are directly of undisputed relevance to society.

Quality and Impact:

- **ERC:** none;
- **NWO VI:** 1 VENI (Bosco);
- **Overall output (2009-2018):** 475 journal papers;
- **Citations (2009-2018)**: 7600 (13 % in top 1% journals; 49 % in top 5% journals);
- **Collaborations**: The research groups have many scientific collaborations and joint research projects with national and international universities and companies on material science and 3D concrete printing, among which the department of Chemistry of the University of Amsterdam, TU Delft, Cambridge University, Wageningen University and Research, NTNU Norway, LBNL Berkeley, Universities in Singapore, France, South Africa Arup, AkzoNobel, SABIC/DSM, Deltares, ENCI, Tata Steel, Mineralz, Van De Bosch Beton, CRH, Inashco, etc. The knowledge of 3D printing in civil engineering will be implemented in the regional Brainport Industry Campus.
- **Worldwide media attention**: Groundbreaking 3D concrete printing projects have received media attention worldwide (CNN, BBC, The Washington Post, The Guardian, Reuters, etc.). The experimental research is supported by state-of-the-art modeling activities, which recently have led to a landmark publication (with media attention) on the mechanistic modeling of structural collapse during 3D printing processes (Suiker, 2018, Int. J. Mech. Sci.).
- **Funding**: by NWO (OTP, HTSM, HTM), H2020, M2i and directly by industry.
- **Unique facilities:** The Structures Laboratory has state-of-the-art facilities for full-scale testing of materials, structural components and structural elements. In addition, the well-equipped Building Physics Laboratories allow for performing high-quality experiments on various physical aspects of materials.

Co-operation and alignment across borders of universities and disciplines

In the above mentioned research field, there is close co-operation and alignment with researchers from Mechanical Engineering at TU/e and Civil Engineering at TU Delft, demonstrated by multiple joint research projects and joint publications. Because of complementing expertise, these co-operations have proven both fruitful and successful and will be continued or even expanded in the future.

Education: MSc program Architecture Building and Planning (60434), track Structural Design and track Building Physics and Services.

Staff: 13 fte permanent staff, proposed *Sectorplan* extension: 4 fte

Table 8-b

Eindhoven University of Technology, discipline of **Civil Engineering**

Subdiscipline & focusgebied	Profilering	Zwaartepunt
* Mechanics of CiE structures	Wind loading on Civil Engineering structures	3. Wind loading on Civil Engineering structures

Wind loading on Civil Engineering structures

The analysis of wind and its effect on civil engineering structures is a highly specialized field of research, in which TU/e has already established a strong basis and unique worldwide position.

We propose to extend our central role in the analysis, prediction and amelioration of wind interacting with civil engineering structures by strengthening research in experimental and numerical modeling of wind dynamics and wind-structure interactions.

This *zwaartepunt* specifically targets the development and evaluation of numerical techniques based on Computational Fluid Dynamics (CFD) for the analysis of wind and its effect on civil engineering structures, with specific emphasis on energy-related structures such as wind turbines (on-shore, off-shore, floating), solar farms in open fields, solar panels on building roofs, etc. A specific focus is the correct representation of the dynamic effects of the wind (gusts, turbulence) and its translation to guidelines and improved codes for the design of energy-related civil engineering structures.

The research into wind-structure interactions focuses on the development of physics models for the understanding of the interactions between the wind loading and the vibrating structure. Special attention will be directed to the optimization of vibration dissipation mechanisms at the micro-scale, thereby making use of energy-friendly materials processed by additive manufacturing. The modeling activities will be supported by dedicated experimental research performed at the Building Physics laboratories and the atmospheric boundary layer wind tunnel in order to accurately describe and understand the process of wind flow, including thunderstorms and downbursts.

Quality and Impact:

- **ERC:** none;
- **NWO VI:** none;
- **Overall output (2009-2018):** 290 journal papers;
- **Citations (2009-2018)**: 5570 (16 % in top 1% journals; 44 % in top 5% journals);
- **Collaborations:** the research group Building Physics is involved in numerous national and international collaborations with universities, research institutes and companies on wind effects on civil engineering constructions including wind energy structures, on vehicles, ships, etc. There is a strong collaboration with numerous universities worldwide but also with leading research institutes such as MARIN (Maritime Research Institute Netherlands), TNO, KNMI and leading multinational companies such as Ansys, Cray (supercomputing), Microsoft and AIRBUS.
- **Worldwide media attention:** recent research work received world-wide media coverage by TV stations such as BBC, France 2, NOS, VRT, and by prominent written media such as the Wall Street Journal, New Scientist, El Pais, L'Equipe, etc.
- **Top ranking:** Research group Building Physics received exceptional recognition by the Academic Ranking of World Universities (Shanghai Ranking), Elsevier and Clarivate Analytics (Web of Science) for worldwide top-citation counts (2016 and 2018). Prof. Blocken is among the 150 most cited researchers world-wide, both in the field of Civil Engineering and in the field of Energy Science & Engineering (source: 2016 Academic Ranking of World Universities (Shanghai Ranking) & Elsevier). He is listed as 2018 Highly Cited Researcher by Clarivate Analytics (Web of Science) for production of multiple highly cited papers that rank in the top 1% by citations for field and year in Web of Science Core Collection.
- **MOOC:** development of TU Eindhoven's first Massive Open Online Course (MOOC) on aerodynamics and wind engineering, which to date has been followed by more than 30,000 students on Coursera.
- **Funding:** by NWO, FWO, H2020 and directly by industry.
- **Unique facilities**: The atmospheric boundary layer wind tunnel, established by Scientific Director Prof. Blocken, is a unique research facility for the performance of state-of-the-art experimental research on wind dynamics. The experimental work is supported by excellent modeling research.

Education: MSc program Architecture Building and Planning (60434), track Structural Design and track Building Physics and Services.

Staff: 4.4 fte permanent staff, proposed *Sectorplan* extension: 3 fte

8.4 Requested positions

In section 8.2 global indications of requested positions have been given. The table below specifies these positions in order of priority.

The *Sectorplan* positions for "Sustainable Civil Engineering Materials and Structures" are linked through various existing research lines and ongoing projects, and these will be further expanded once the sector plan positions are in place. For instance, the 3D printing of concrete structures (position 2) is characterized by a coupling of mechanical, thermal and chemical curing effects, which requires a multi-physics modelling approach (position 3). Concrete mixtures required for 3D printing (position 2) will be developed from material research (positions 4 and 6). New, sustainable and light materials (developed in position 3) will be used in wind energy structures which are tested within positions 1, 5 and 6. Position 6 is closely connected to the TU/e Institute for Renewable Energy Storage and will be strengthened by funds from the institute in the form of PhD candidates and PDEng trainees.

Table 8-c Requested Positions Discipline of Civil Engineering

Eindhoven University of Technology, discipline of **Civil Engineering**			
Priority	*Position*		
Versterkt zwaartepunt		*Position level*	
1	**Experimental Wind Dynamics**		
Wind loading on Civil Engineering structures		Junior Experimental	
Experimental research will be performed in the atmospheric boundary layer wind tunnel in order to accurately describe, analyze and understand the process of wind flow and its interaction with civil engineering structures. *Related research*: Blocken, Schellen, Van Hooff, Montazeri, Hornikx, Hak, Salet, Wijte, Bos, Simaria de Oliveira Lucas. *Collaboration*: TU Delft, ETH Zürich, MARIN (Maritime Research Institute Netherlands), TNO, KNMI, KU Leuven, Concordia University.			
2	**Optimization of 3D-printing of Civil Engineering Structures**		
Sustainable Civil Engineering Materials and Structures		Junior Theoretical	
Development of numerical shape and topology optimization tools for the 3D printing of civil engineering structures with complex shapes, using as little material as possible. Mechanistic modeling to accurately predict the structure both during and after the printing process. *Related research*: Salet, Wijte, Bos, Simaria de Oliveira Lucas, Suiker, Hofmeyer, Bosco. *Collaboration*: Nanyang University of Technology (NTU), Singapore, IFSTTAR Paris University of Stellenbosch, TalTech University, University of Innsbruck, TU Delft Experimental Micromechanics, ETH Zurich, University of Napels.			
3	**Multi-physics Behavior of Durable Civil Engineering Materials**		
Sustainable Civil Engineering Materials and Structures		Junior Theoretical	
Analysis and prediction of mechanical behavior of civil engineering materials by means of coupled multi-physics models, in order to arrive at new materials with improved durability characteristics. *Related research*: Suiker, Hofmeyer, Bosco, Salet, Wijte, Bos, Simaria de Oliveira Lucas. *Collaboration*: Cambridge University, Wageningen University and Research, TU Delft, Getty Research Institute.			
4	**Circularity of Cementitious Civil Engineering Materials**		
Sustainable Civil Engineering Materials and Structures		Junior Experimental	
Research into the improvement of the packing efficiency of irregular, angular shaped secondary aggregates, and the optimization of the reactivity and hydration behavior of cementitious supplementary materials. *Related research*: Brouwers, Van der Laan, Yu, Van Schaijk, Salet, Wijte, Bos, Simaria de Oliveira Lucas, Hensen, Kort, Hoes, Loomans, Loonen. *Collaboration*: Wuhan University of Technology, State Key Lab of Silicate Building Materials, Bundesanstalt für Materialforschung und Prüfung.			

<table>
<tr><td>5</td><td colspan="3">Wind-Structure Interactions</td></tr>
<tr><td colspan="2">Wind loading on Civil Engineering structures</td><td>Junior Theoretical</td><td></td></tr>
<tr><td colspan="4">Development of physics models for understanding the interactions between the wind loading and the vibrating structure. Optimization of vibration dissipation mechanisms at the micro-scale, making use of energy-friendly materials processed by additive manufacturing. The modeling activities will be complemented by experimental research.
Related research: Hornikx, Hak, Blocken, Schellen, Van Hooff, Montazeri, Suiker, Hofmeyer, Bosco.
Collaboration: Ghent University, Aalto University, Stockholm University.</td></tr>
<tr><td>6</td><td colspan="3">Energy Generation, Storage and Distribution in Civil Engineering Structures</td></tr>
<tr><td colspan="2">Sustainable Civil Engineering Materials and Structures</td><td>Junior Theoretical</td><td></td></tr>
<tr><td colspan="4">Development of new solutions for energy generation, storage, distribution and demand reduction, and integration and optimization in the design, construction and operation of new and existing civil engineering structures, in order to achieve zero-impact materials and structures from a performance-based perspective.
Related research: Hensen, Kort, Hoes, Loomans, .Loonen
Collaboration: Eurotech universities, Czech Technical University, TU Delft, REHVA, Aalto University.</td></tr>
<tr><td>7</td><td colspan="3">Numerical Modeling of Wind Dynamics</td></tr>
<tr><td colspan="2">Wind loading on Civil Engineering structures</td><td>Junior Theoretical</td><td></td></tr>
<tr><td colspan="4">Development and evaluation of numerical techniques based on Computational Fluid Dynamics (CFD) for the analysis of wind and its effect on civil engineering structures, with specific emphasis on energy-related structures such as wind turbines (on-shore, off-shore, floating), solar farms in open fields, solar panels on building roofs, etc. A specific focus is the correct representation of the dynamic effects of the wind (gusts, turbulence) and its translation to guidelines and improved codes for the design of energy-related civil engineering structures.
Related research: Blocken, Schellen, Van Hooff, Montazeri, Hornikx, Hak, Hensen, Kort, Hoes, Loomans, Loonen, Suiker, Hofmeyer, Bosco.
Collaboration: TU Delft, ETH Zürich, MARIN (Maritime Research Institute Netherlands), TNO, KNMI, KU Leuven, Concordia University.</td></tr>
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8.5 Targets and Monitoring

Diversity of staff and students

Increasing diversity of staff has been key part of the department board's recruitment strategy in the past years, demonstrated by the fact that since 2015 40% of newly recruited scientific staff within the discipline of civil engineering was female. The same percentage applies to the diversity in nationality of recruited staff, i.e., 40% is non-Dutch.

As per the university's general policy on diversity and gender balance, every recruitment and promotion assessment committee has at least 2 female members. Also, each vacancy description is screened for implicit gender-bias by an HR-advisor who is trained for this.

With regards to student recruitment, we have successfully improved our communication to prospective students by increasing the emphasis on societal relevance and the direct impact on society that our graduates have. It is proven that this aspect plays an important factor in the study choice of young women, which is demonstrated by the successful increase of female students to approx. 35%.

Again, the same percentage applies to the diversity in nationality of students, i.e. approx. 35% is non-Dutch. We are confident that we will be able to continue these upward trends and reach a 40% share.

Societal collaborations and dissemination of knowledge

Apart from strong academic collaborations with world leading universities, the civil engineering groups have established fruitful collaborations with leading industrial and multinational companies (such as Ansys, Cray, Airbus, ENCI, CRH, Inashco, AkzoNobel, Arup, Saint-Gobain and others) and esteemed research institutes (such as MARIN, TNO, Deltares, KNMI and others). Several full professor positions are wholly or partly funded partners (TataSteel, TNO, Hogeschool Utrecht, Witteveen+Bos, Hageman) as well as departmental fellowships (Nieman and Stichting WOI). A consortium of partners (joined in legal entity SPARK Campus) funded 16 PhD positions, of which the first batch of PhD candidates will be obtaining the doctorate degree this year.

Partnerships have also been established with Dutch universities of applied sciences (e.g. HAN, Avans, Hogeschool Utrecht, HS Zuyd, Fontys), which include seamless learning pathways for students, co-operation in research projects, supervision of lecturers for obtaining a doctorate degree (currently 8 PhD candidates), and cross-institutional student teams participating in (inter)national competitions.

With the regional Summa College (intermediate vocational education) a long-term partnership exists for education and knowledge advancement of teachers in technical subjects.

The department has the ambition to act as a catalyst and play a central role in the regional quadruple helix innovation ecosystem. As described previously, the 'Brainport Smart District' is an exceptional initiative by TU/e, which is being realized in cooperation with public partners, companies and citizens from the Brainport region. It is the world's first truly 'smart' district, which contains 1500 houses and will be a unique living lab, in which all new and smart technologies are to be integrated in a renewable, social and attractive living district, with the ultimate goal to improve the quality of life of the inhabitants. The future inhabitants are closely involved in the development of 'their' district. Other highly interesting research applications realized in collaboration with societal partners include the realization of the first bridge (2017) and the construction of the first houses (expected in 2019) in the world by 3D concrete printing technology, and the building of a bio-based composite bridge (2016).

Apart from consolidating existing collaborations, the groups actively pursue expansion by participating in national and international programs, alliances and consortia. Researchers contribute to societal developments with regards to the energy transition (Taskforce Bouwagenda, BTIC program committee) and circularity (chairmanship national transition team towards a circular building economy, as part of the governmental program 'Netherlands 100% circular in 2050 by RVO/BZK), are member of professional networks and participate in consortia in several NWA-routes and H2020 programs.

Researchers are frequently interviewed by national and international media. Several professors have obtained a status of go-to expert, for their views on current topics such as structural collapses, smart cities, renewable energy and wind dynamics. Recent examples include the collapse of the parking garage at Eindhoven Airport and the use of bubbledeck floors related to this, the closure of the Merwede bridge, the structural safety of the grandstand of the NAC Breda soccer stadium, the transition to gasless infrastructure, the performance of wind energy turbines in the Bahrein WTC, colleges for the *Universiteit van Nederland* about renewable energy and the cities of the future and so on.

In this same regard, Open Science is an important current topic in relation to sharing knowledge and research results with society. The department has appointed a data steward to support researchers with matters related to FAIR research data management, open access, long-term storage, deposit of datasets et cetera.

Other targets

With respect to other targets, we aim at consolidation or gradual growth. We expect the Atmospheric Boundary Layer Wind Tunnel to have a significant share in the increase of industrial collaboration.

Numerus Fixus: the extra *Sectorplan* positions will allow us to raise the *numerus fixus* in 2020 to 300 (current cap on 275). We will evaluate in 2020 whether an even higher influx can be accommodated and adjust or cancel the cap accordingly.

Table 8-d Staff targets – discipline of Civil Engineering

Eindhoven University of Technology, discipline of Civil Engineering	
	2024
Permanent scientific staff (fte)	17
Tenure trackers (fte)	14
Post-docs (fte)	12
Women in permanent scientific staff (fte)	3
Women in tenure trackers (fte)	6
Women in post-doc positions (fte)	5
Percentage of women appointed in sector plan positions	35%

Table 8-e Quality and relevance indicators targets – discipline Civil Engineering

Eindhoven University of Technology, discipline of Civil Engineering		**Target 2024**
Quality	Competitive grants (ERC, NWO) *(last 2 years; in parentheses: all)*	
	Number of awards (Spinoza, Stevin, IEEE-level, etc.)	
	Number of papers *(FWCI; % in top 5% Journals)*	
	Other parameters of esteem	
Relevance	NWA grants in M€	
	Topsectoren grants in M€	0.3 M€/year
	Societal collaborations (narrative)	
	Number of patents	0/year
	Number of Start-ups / spin-offs	1/year
	Industrial collaborations in M€	3.5 M€/year
	Funding in 2^{nd} and 3^{rd} tier (M€)	2^{nd}: 1.6 M€/year 3^{rd}: 3.5 M€/year

Table 8-f Education targets – discipline Civil Engineering

Eindhoven University of Technology, discipline of Civil Engineering	
	2024
Intake bachelor students	130
Percentage female	40%
Intake master students	90
Percentage female	40%
Success rate BSc-diploma's	80%
Success rate MSc-diploma's	75%
Nr of PhD theses	15
% of PhD theses from women	35%
Nr of Pdeng theses	8
% of PDeng theses from women	40%