2013-2018

Research Self Assessment

TU/e

EINDHOVEN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF MECHANICAL ENGINEERING

Self-assessment

Preface

This research report is the self-assessment of the Department of Mechanical Engineering over the period 2013–2018. It follows the SEP-protocol (Standard Evaluation Protocol), established by the KNAW (Royal Dutch Academy of Science). This protocol calls for a new way of presenting: emphasis is on prospective aspects, rather than on retrospective aspects.

The future of the Department is bright. The developments in the years 2013–2018 have made us better and stronger. Substantial budget increases appear at the horizon, coming from both within TU/e and from national initiatives taken by the Ministry of Education. Our newly developed strategy *Mechanical Engineering TU/e beyond 2020* enables the Department to tackle these positive challenges in a coherent way, to bring our staff to the international top, and to optimally profit from the unique high-tech industrial ecosystem in the immediate vicinity.

Prof.dr. L.P.H. de Goey
Department Dean
November 2019

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ME: Core of TU/e as Dutch High-Tech Systems University

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The *mission* of TU/e is to advance knowledge and to educate tomorrow's engineers & scientists. We work at the forefront of science & technology, within the high-tech systems knowledge and innovation ecosystem of Brainport Eindhoven. In this ecosystem some of the world's most advanced intelligent machines and electronic systems are developed and we supply the vast majority of engineers to this ecosystem. In close collaboration with public and private partners, we translate 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.

TU/e takes the *strategic* step to strengthen its profile as *the* Dutch *High-Tech Systems University*. We are increasing our capacity to educate engineers, to invest in Science and Engineering disciplines, to establish Institutes for cross-disciplinary research that integrate basic disciplines in solutions for society, and to create partnerships that increase scientific and societal impact.

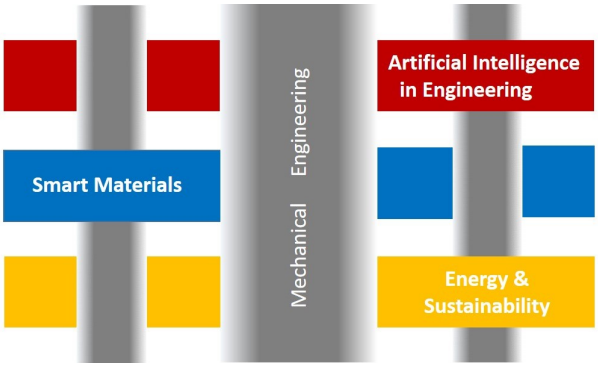
Three *cross-disciplinary research themes* form the pillars of the TU/e as a High-Tech Systems University:

1. Artificial Intelligence in Engineering
2. Smart Materials
3. Energy & Sustainability

Mechanical Engineering delivers core disciplines for each of these themes as described below.

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. 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. Within the context of the recently established EAISI institute new technologies will be developed to integrate hard- and software into systems that become increasingly 'intelligent', autonomous and interconnected. The development of intelligent and interactive autonomous systems poses challenges on sensing, control (world) modeling, human-machine interaction, system design (big-)data management and algorithm design. Within the department of Mechanical Engineering research is directed towards modeling, sensing and control for complex autonomous systems, and autonomy in (vehicular) transportation systems.



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. Within the department of Mechanical Engineering the focus is on development and manufacturing of designer materials, which 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, metamaterials, programmable materials, etc. Of key importance is the manufacturing thereof, in which multi-material additive manufacturing takes a central position.

Energy & Sustainability

Energy & Sustainability is a theme that has a central position in the TU/e Sector plans 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). 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).

The Department

1 Profile of the Department

1.1 Introduction

In this section the profile of the department is summarized. In subsequent sections more information is provided.

1.2 Overview

The department of Mechanical Engineering (ME) is one of the nine departments of Eindhoven University of Technology (TU/e). The department was established at the founding of the university in 1956. Since the mid-1990s, the structure of the department has gradually evolved into a three-level organization, consisting of clusters, sections and groups. Each *cluster* consists of a number of *sections*, and each section consists of a number of *(principal investigator) groups*. The organizational structure of the department is shown in Fig. 1.

There are three research clusters: one with a focus on mechanics and materials (Computational and Experimental Mechanics, CEM), a second one with a focus on systems, dynamics and control (Dynamical Systems Design, DSD), and a third with a focus on heat and flow (Thermo Fluids Engineering, TFE). The research clusters are not part of the formal governance structure of the department. The clusters aim to integrate fundamentals, design and manufacturing in a specific research area. In each of these clusters several sections collaborate in the educational program and often share lab research facilities and technicians. All research clusters are conceptually and methodologically oriented, rather than exclusively focused on either applications or fundamentals.

As of 2019 there are seven sections. Each section consists of a number of research groups, led by a principal investigator (usually a full or associate professor). In principle a research group leader is held responsible for the funding of research in the research group, though budgets are still handled at the section level.

Table 1 (page 18) shows the composition of the scientific, visiting and supporting staff for the entire department. All sections consist of multiple research groups, adding up at the section level to 1–3 full professors, several assistant and/or associate professors, part-time professors mostly from industry, a few technicians (shared with other sections), a secretary plus temporary scientific personnel, PhD students and postdocs. (Temporary not-on-payroll staff members are included in the numbers, as they also contribute to the volume of work done within the department.) There are around 2000 engineering (BSc and MSc) students.

The industrial surroundings of the department are characterized by an exceptionally high concentration of high-tech industry and research & development lab-

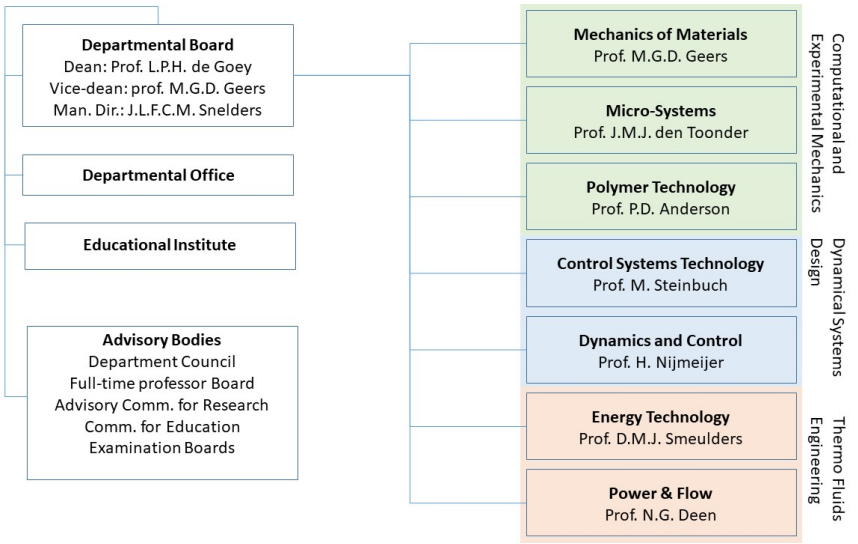


Figure 1: Organogram of the Mechanical Engineering department (Jan. 2019): the three research clusters are depicted as colored boxes that contain the sections they consist of. The research groups are not shown in this organogram.

oratories, which are all competitive on a global scale. Within the supply chain, large companies focus on carefully selected core technologies, while small and medium-sized enterprises concentrate on subsystem analysis, design and manufacturing. TU/e, and ME in particular, play an important role as a core partner in Brainport Eindhoven[1], an innovation ecosystem driven by municipalities in the region surrounding Eindhoven, national and international companies and knowledge institutes. This involvement has a significant impact on the research, since this stimulates research initiation, validation and uptake.

1.3 Mission statement

Within this historical and industrial context, the mission of the department can be stated as:

- To carry out long-term, generic, world-class research within the mechanical engineering domain on carefully selected topics that fall within the research profile areas of the university, and that match the technological interests of high-tech, internationally oriented industry in the Netherlands and especially in Brainport Eindhoven.

1. https://brainporteindhoven.com/

- To realize an education and research program with a balanced combination of fundamental and application aspects, thereby aiming at providing industry with scientifically educated and application-driven engineers who are optimally equipped to address future challenges.

1.4 Education at BSc and MSc level

The Mechanical Engineering Bachelor's program is part of the Bachelor College of TU/e and consists of a broad disciplinary basis and five major learning lines in Mathematics, Design and Manufacturing and a learning line related to each of the three research themes (Energy and Flow, Materials and Mechanics, and Systems, Dynamics and Control). These research themes are also the internationally recognized subdisciplines of mechanical engineering.

The Mechanical Engineering Graduate program is part of the Graduate School of TU/e, and incorporates the ME Master and PhD program. The ME Master program consists of a core part and a socialization part related to one of the seven sections. The faculty members of the department provide most of the teaching elements in the Bachelor's and Master's program.

Additionally, the department chairs and steers several other inter-departmental graduate programs: Automotive Technology (AT), Systems & Control (S&C) and Sustainable Energy Technology (SET). Both the bachelor and master programs in Mechanical Engineering and these inter-departmental graduate programs contain courses that are lectured or co-lectured by staff from other departments.

1.5 Organizational structure

The Departmental Board, appointed by the Executive Board of the university, consists of the Dean, the Vice-Dean and the Managing Director (see Figure 1). The educational directors and a student act as advisors and also attend the weekly Board meetings. The Dean is ultimately accountable for the entire management, in which the Managing Director covers all matters concerning personnel and organization, financial administration, services and accommodation.

The department has a professional managerial structure including direct communication between the Departmental Board and the individual sections. The department has an educational institute to organize the educational programs, and its own management support sections for human resources, finance, computing, accommodation and maintenance. All major administrative support systems are integrated university-wide.

The Departmental Board has a number of permanent advisory bodies that play a role in its decision-making procedures:

- the *Departmental Council*, consisting of representatives of students and personnel and which has to approve major organizational and educational changes as well as the annual budget,
- the *Full-time Professor Board*, which meets once every two weeks to share information and discuss important strategic choices of the department,
- the standing *Advisory Committee for Research*, which advises the Departmental Board on policies in quality control of research,
- the standing *Committees for Education* of the educational programs, which advise on educational policies and on the educational programs,
- the *Examination Boards* of the educational programs, independent committees that decide on all formal matters related to examinations and diplomas.

For specific purposes ad hoc committees may be erected to advise the Departmental Board.

The major communication channel is through the meetings of the Departmental Board and the Full-time Professor Board. Subsequently, each section leader communicates on a regular basis within his/her section. A news page on the department website[2] provides relevant up-to-date newsflashes.

In addition, the department organizes the following annual meetings:

- between the Board and each section leader to discuss personnel development and career planning of all section members,
- between the section leader and each research group leader to discuss performance and strategy of the research groups and section,
- between the Dean and each section leader to evaluate the performance of the section and the section leader, the departmental strategy and strategy of the section,
- an annual 'Research Day' at which the scientific staff (professors, associate professors and assistant professors) meets to discuss research highlights, offering a platform to new faculty members to present their research plans,
- an annual 'Education Day' all staff involved in education meets to discuss the most recent developments regarding the university's and department's policy on education, new curricula and educational tracks.

1.6 Embedding of the department at the university and national levels

The university is organized in a matrix structure with 9 disciplinary oriented departments. A number of established and upcoming institutes provide an umbrella

2. https://www.tue.nl/en/our-university/departments/mechanical-engineering/

under which research groups from different departments are stimulated to cooperate on research themes that have been labeled as both scientifically challenging and societally relevant. Sections of ME participate in the following institutes:

- Institute for Renewable Energy Storage (IRES): with sections ET and PF
- Eindhoven Artificial Intelligence Systems Institute (EAISI): with CST and DC
- Institute for Complex Molecular Systems (ICMS): with DC, MS and PT
- Materials & Quantum Nano-Photonics (QNP): with MoM

Investments through these institutes are intended to finance start-up packages for new scientific positions, facilities for research infrastructure such as laboratory equipment, and cross-disciplinary or joint research.

Recently the Eindhoven Engine[3] came into existence. The goal is to foster cooperation along the entire knowledge chain, from basic research to market. Teams of our region's most talented researchers from industry, knowledge institutes and students will cooperate in Eindhoven Engine research programs to deliver breakthrough technological solutions. Eindhoven Engine will accelerate innovation in Brainport Eindhoven through challenge-based research in its public-private research facility at the TU/e Campus.

Nationally, the focus is on 4TU.Research Centers, Leading Technology Institutes and Graduate Schools. The three Dutch universities of technology – Twente, Delft and TU/e – collaborate since 2005 in the 3TU joint venture to coordinate research and education in technical engineering sciences in the Netherlands. Wageningen University and Research (WUR) joined in 2016 constituting 4TU since then. The department participates in the following Research Centers:

- High-Tech Materials (4TU.HTM): with section MoM
- Fluid and Solid Mechanics (4TU.FSM): with ET, MoM, MS, and PF
- Resilience Engineering: with ET
- Energy: with ET and PF

At the national level the department substantially participates in two Leading Technology Institutes (TTIs or LTIs):

- Dutch Polymer Institute (DPI), in which PT participates, and
- Materials Innovation Institute (M2i) in which MoM and PT participate.

3. https://eindhovenengine.nl/

The LTIs provided substantial external industrially oriented research funding in the period until 2015, with a structural link between the research carried out by the participating groups and industry. The structural governmental funding has stopped in recent years, but with the industrial support provided, the LTIs continue where possible with their interfacing role between industry and academia.

1.7 Personnel

Table 1 shows the composition of the scientific, visiting and supporting staff for the entire department. All established sections consist of multiple research groups, adding up at the section level to 1–3 full professors, several assistant and/or associate professors, part-time professors mostly from industry, a few technicians (shared with other sections), a secretary plus temporary scientific personnel (PhD students and postdocs).[4]

Table 1: Composition of research and support staff in pye.

Research staff	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Scientific staff	64.0	61.5	57.6	58.8	57.0	56.9
Post-docs	21.6	23.8	18.6	22.8	26.3	19.2
PhD students	151.3	149.1	142.4	163.4	160.8	165.9
Total research staff	**236.9**	**234.4**	**218.6**	**245.0**	**244.1**	**242.0**
Support staff	58.1	57.2	52.0	48.7	44.6	40.5
Total staff	**295.0**	**291.6**	**270.6**	**293.7**	**288.7**	**282.5**

The volume of tenured research staff has decreased over the past few years. The number of PhD graduates increased over the evaluation period, which is a result to be proud of. The main reason for this increase in number of PhD students is the TU/e Impuls program where industry-funded PhD positions are matched by university-funded PhD positions. Currently, the PhD student/tenured staff ratio (based on research fte) has reached a value of slightly exceeding 7, which is equivalent to an average of 3 PhD students per faculty member. This means that the objective, formulated in the self-assessment of the previous evaluation period, has been reached. Technical staff are embedded in the laboratories / divisions, shared by several sections. The sections share a joint responsibility for their technicians, which enhances flexibility and efficiency and allows the ratio of technical staff

4. Standard PhD (employed) and Contract PhDs (externally or internally funded but not employed). Tenured scientific staff members are involved for 40% of their time in research, postdocs and PhD students for 80%. Unit *pye*, short for *person-year-equivalent*, is time-averaged fte, i.e. a three-month 0.8 fte appointment counts as 3/12 × 0.8 fte = 0.2 pye.

to scientific staff to be kept low. The technical supporting staff/tenured staff ratio has decreased by 30% as a consequence of increased efficiency and a departmental strategy to focus on technical staff that is embedded in the research of the department. This reflects the Board's intention to have a more 'lean' support structure.

Recruitment, tenure and promotion

For recruitment of new assistant/associate/full professors, for evaluating temporary faculty members for whom tenured positions are planned, and for internal promotions the department appoints a recruitment committee with a prescribed composition that guarantees a certain broadness as well as in-depth expertise (members are invited from the TU/e-broad Interfaculty Committee Engineering and from other (Dutch) universities)[5]. In addition, to reduce gender bias as much as possible, also a minimal female participation is required.

In each of the above-mentioned cases, the process follows university regulations. After a positive recommendation by the committee, the Departmental Board decides and if required (in case of full and associate professors) prepares a proposal for the Doctorate Board of the university. The Executive Board of the university will finally confirm the appointment. New faculty members are in principle given a temporary appointment for a five-year period, during which tenure is given if suitable. Each newly appointed faculty member is provided with a starting package to help setting-up the research profile. For an assistant professor this is 250 k€, for an associate professor 350k€ and for a full professor 500 k€.

The department has an active policy of appointing scientifically oriented part-time assistant/associate/full professors (generally 0.2 fte) from industry (providing a structural link with industrial applications), and from technological institutes (such as TNO, the Netherlands Organization for Applied Scientific Research), and from other universities. The aim of these industrial appointments is to introduce industrial experience into the research and education. Currently, 14 part-time professors, 5 part-time associate professors and 9 part-time assistant professors are appointed, for example from Shell, Philips, DSM, ASML, ECN, Vanderlande Industries, TNO, FOM DIFFER, University of Twente, Delft University of Technology and University of Amsterdam.

Diversity in relationship to recruitment, tenure and promotion is described in more detail in Section 4, which relates to the special Standard Evaluation Protocol (SEP) themes.

5. A full set of university regulations is provided in Appendix 11

Development and evaluation
All new faculty members attend a number of courses on management, presenting, research, education and teaching.

- A general management course aimed at improving leadership skills for professionals.
- Courses that include didactical training, presentation techniques, design of new courses, design of examinations and tutor and mentor training, as well as language courses.
- Requirements for teaching are governed by the University Teaching Qualifications (UTQ), which is a set of basic teaching qualifications for university teaching personnel, as established country-wide in the Netherlands and for which rules are defined at 4TU level. At present, 83% of the scientific staff have qualified for UTQ. The remaining faculty members are in the process of acquiring UTQ, or close to retirement. Two faculty have obtained the certificate Educational Leadership.
- Training programs in project management are stimulated and available on request.
- The department encourages financed sabbatical leaves by faculty members every five years. A stay abroad is considered important for international contacts, research refreshment and internal promotion.
- An annual evaluation of all personnel is performed covering both performance and job satisfaction. Full integration of education and research in the tasks of the tenured scientific staff is considered essential.

1.8 Financing and facilities

Overview of funding in 2013–2018
The funding of the department is split into (1) direct funding from the university board and (2) additional research grants (second tier) and contract research (third tier) funding.

(1) At present, the net effect of the *direct funding* is that the board provides the salaries of the staff members, and the costs of the buildings that are empty but including heating and lighting. All other funds are to be acquired externally (from second and third tier funding). The department's total annual budget of direct funding of 11–13 M€ is split into three parts:

- Staff salaries (scientific and support) directly funded by the department ($\pm$ 55%)
- Funds needed for education and administrative tasks ($\pm$ 30%)
- Funds to support new sections and groups for a time period of 5 years and funds for strategic support of sections and groups ($\pm$ 10%).

The first two are funded directly at departmental level, covering the major part (± 90%) of the direct funding. This creates long-term stability in the department's personnel policy. The remaining strategic budget (± 10% of the direct funding, typically 1 M€) is used by the departmental board to invest strategically, e.g. in personnel and in laboratories to support the sections and research groups by providing them with a proper research infrastructure. The part of direct funding assigned to the sections for exploitation is meant to support especially young faculty members (e.g. PhD students and starting packages for new faculty members).

(2) *Second and third tier funding* (approx. 10–12 M€) from governmental agencies such as NWO (Netherlands Organization for Scientific Research), NWO domain Science, technology foundation NWO-AES, Leading Technology Institutes (Materials Innovation Institute, Dutch Polymer Institute), TKIs, European projects, innovation programs and from industry is directly managed by the research group that acquired the project. The TU/e and the ME department do not impose overhead on these grants. The funded overhead costs of all projects are exploited at the section level, with all its constituting research groups. Sections are expected to manage the full exploitation of their remaining costs from these overheads. This structure allows the different research groups in a section to support each other in maintaining a positive financial balance over the years. See Table 2 for the funding of research in the sections and research groups.

Table 2: Funding at section level (in M€)

Funding	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Direct funding[6]	0.0	0.1	0.4	0.9	1.3	1.3
Research Grants[7]	4.3	4.9	4.2	3.9	4.1	4.4
Contract Research[8]	5.9	5.8	6.3	6.5	6.4	6.2
Total funding	10.2	10.8	11.0	11.3	11.8	12.0
Expenditure:						
Personnel costs	7.3	7.2	6.9	7.6	7.7	7.7
Other costs	2.9	3.6	4.1	3.7	4.1	4.3
Total expenditure	10.2	10.8	11.0	11.3	11.8	12.0

6. Direct funding by the university, for research. This is not the direct funding for the departmental level.

7. Research grants obtained in national and international scientific competition (e.g. grants from NWO, KNAW and European Research Council) including FOM revenue & Zwaartekracht revenue personnel.

8. Research contracts for specific research projects obtained from external organizations, such as industry, governmental ministries, European Commission, and charity organizations. Including M2i revenue.

In the years 2014 and 2015, the department faced a financial loss of around 1 M€ per year (see Table 3). This loss was primarily related to a strong decrease in direct funding at the department level. As a result, a serious restructuring process was carried out in the department by cutting costs within the department and sections, which was made possible without any personnel replacements. On the other hand, plans to invest had to be postponed. Furthermore, to be more robust for future fluctuations in the budget, the department decided to merge several smaller sections to make them more financially robust. This has been successful and the strategic budget from 2017 onwards is significant again (larger than 1 M€ per year). Presently, the strategic budget is approximately 1–2 M€ per year, typically to be used for starting packages and first tier PhD student projects.

Table 3: Financial results (in M€)

Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Result	-0.3	-1.5	-0.6	0.2	1.0	0.7

General observations related to the funding are:

- The direct government funding allocated by the university Executive Board to the department is rising due to increased numbers of bachelor and master's students and PhD theses.
- External funding by research grants and contracts increased over the years and remained at a relatively high level after a strong increase during the previous evaluation period between 2006 and 2011.
- To promote the acquisition of external projects, the Departmental Board has adopted a policy of not levying overheads on the external funding within the sections. This strategy ultimately provides sections and research groups the necessary funds to maintain infrastructure and temporary manpower needed to carry out the research.

Housing and research infrastructure

The sections have an excellent laboratory infrastructure. In the assessment period the department and its groups have substantially renewed the experimental facilities. Currently the department hosts the following laboratories per cluster. A * indicates that the laboratory is a TU/e laboratory, which means that these are supported by the university and that their facilities are also used by other departments and industrial parties.

- Computational and Experimental Mechanics
  - Mechanical Testing laboratory
  - Microfab laboratory*
  - Multiscale laboratory*
  - Polymer Processing laboratory
  - Rheology laboratory
  - Simulation laboratory
  - Structured fluids & additive manufacturing laboratory
- Dynamical Systems Design
  - Automotive Engineering Science laboratory
  - Constructions & Mechanisms laboratory
  - Medical Robotics laboratory
  - Motion laboratory
  - Robotics laboratory
  - Systems Engineering laboratory
- Thermo Fluids Engineering
  - Darcy laboratory*
  - Future Fuels and Zero Emission laboratory*
  - TFE laboratory

Also other labs than the mentioned TU/e labs are used by other departments.

For the design, engineering and construction of high-tech or complex equipment, the university operates the Equipment and Prototype Center (EPC), a workshop which is well equipped for high-precision machining for mechanical constructions and design, and for stable, easy-to-align support structures. Research clusters have joint, well-equipped workshops for quick adjustments and building of small experimental set-ups.

Currently the Zero Emission laboratory is under reconstruction. A full renewal of the Gemini buildings, the department's current home base, is expected to be undertaken in the period 2021–2025.

2 Strategy

2.1 Strategy concerning research organization

The strategy adopted by the department is oriented towards maintaining and intensifying its proven excellence in research quality, research relevance and research output in a balanced combination with its state-of-the-art teaching and education of substantial numbers of BSc and MSc students. The department strives

for excellence, in both research (order 150 PhD students) and education (order 300 freshmen). As a result, the faculty members are always actively involved in the educational programs. Ideally, 40% of a faculty member's time is spent on research, 40% on educational tasks and 20% on other tasks such as management and personal development. As a guideline, each (assistant/associate) professor supervises 3 PhD students and several BSc and up to 5 MSc students. PhD students are encouraged to participate actively in the international research community and to interact with their peers, by contributing to international symposia and congresses and publishing in high-impact refereed journals.

The Departmental Board adopts a flexible strategy, which is responsive to internal and external developments. The Board especially recognizes the increase in workload of the tenured scientific staff through the decreasing success rates in external funding and, most importantly, by the strongly increasing number of students.

Key objectives of the department Board policy are to:

1. Seek balance between research and educational duties for faculty members;
2. Organize sections, groups, labs and department such that
   - each faculty member is able to work independently in a coherent group structure which optimally supports his research and educational activities;
   - cooperation across organizational units in both research and educational activities is stimulated;
   - faculty members are protected from individual administrative overload and financial constraints by organizing formal administrative, educational and financial responsibilities jointly at the section level;
3. Support and facilitate faculty with research funding opportunities within the possible constraints of the university funding structure.

The following actions are taken by the Board to reach these objectives:

1. The Departmental Board introduced several measures in order to secure the delicate **balance between research and educational work**. The total number of students in the Bachelor and Master programs almost doubled from 1300 in 2013 to 2000 in 2018. This entailed an increase of the educational part of the direct funding, which could not be immediately compensated by the required increase of staff and facilities. The student/staff ratio increased from 20 to 33 in the time period between 2013 and 2018, accounting for all students of the Bachelor and all Master programs in which the department is involved. Even more important is that the students are not distributed proportionally over the research clusters, sections and groups. The CST and DC sections are traditionally popular and the Board therefore introduced several measures to distribute the

Master students between the different sections, by limiting the total number of supervised students per section on the basis of the size in terms of faculty. This measure also better protects our faculty against the growing workload and pressure. As the inflow seems to increase further in the future, the Board also decided to set a maximum inflow in the Bachelor to 330 students in 2019, which is considered to be the maximal capacity in a steady state with around 66 faculty members. The rationale behind these actions is to limit the number of supervised Master students to 5 per faculty member.

2. The **organization of the department and sections** is optimized on the one hand to reduce the overhead and stimulate collaborations within and between the sections and on the other hand to give individual faculty members as much responsibility as possible for their own research. The departmental board uses its strategic research funds to stimulate PhD projects across research groups and sections.

   Within the separate sections, management tasks are mostly distributed among the faculty members, while there is still one section leader among the full professors in the group, who is responsible for the personnel and overall financial management of the section. In 2012, the department consisted of 14 smaller sections, but in 2014–2016 it appeared necessary to merge and combine several smaller sections to make them less vulnerable to fluctuations in funding. The board is in principle open to create, merge, or split sections in order to obtain the right balance in independence, resilience and vulnerability.

3. The following strategy is adopted for appointing **personnel in the department** in the coming years. To cope with the growth of students and related (but delayed) increase in direct funding the board plans to appoint 30 more faculty members in different areas (see Section 2.4). Additionally, the tenured technical staff in the labs has been reduced to a core tenured team in the last decade. The goal is to create more flexibility in the technical staff by opening additional temporary positions, partly financed from research and contract grants of the sections.

4. Appointment of **personnel and direct funding** go hand in hand. To enhance collaboration between sections as much as possible, all faculty members, the core technical staff, educational institute, the services and the infrastructure are financed by the department board from direct university funding. Sections finance their own lab infrastructure and computing facilities and temporal scientific staff members (PhD/PD's) from industry and research funding. Accordingly, faculty members are only responsible for the funding of their own research projects.

5. The above-mentioned strategy stimulates faculty and groups to acquire **research funding**. The groups have been quite successful in acquiring external funding via a variety of funding channels. The board stimulates and supports

groups to create long-term collaborations with industrial partners. As an example, so-called Impuls-programs with major industrial partners were introduced in 2013 (Impuls I) and 2015 (Impuls II). Each PhD project fully financed by industry was supplemented by direct funding of another PhD student by the university Board. The department was very successful and appointed 120 PhD students in this way. And more importantly, this enhanced our long-term relation with key industrial partners.

Personal grants are another example. Due to the high quality and reputation of our staff, there are good opportunities to receive more national (NWO Veni-Vidi-Vici) and European (ERC) personal grants. The departmental board stimulates, advises and (financially) supports faculty members to develop such grant proposals. In the years 2013–2018 seven such personal grants were awarded to faculty (see Section 3.2 for an enumeration).

The department does not apply any overhead on acquired research funds; all the funds go to the involved research groups and sections. This has stimulated a significant increase of submitted proposals to acquire personal grants. Moreover, the recent reorganization of sections into independent research groups is expected to stimulate faculty to submit competitive project proposals. Currently the department employs three program managers (as part of the university-wide research support network) that assist the scientific staff in the preparation of project proposals, and exploration and initiation of new research activities and collaborations.

6. **Research infrastructure and labs** are of key importance for the research in a ME department. Our department has several world class labs, as mentioned before. The infrastructure is financed by direct funding while contract/research funds from the groups, including strategic funds from the board, are used to develop, optimize and maintain the experimental facilities. The departmental board stimulates researchers to integrate the labs into larger combined units, increase their visibility, make them accessible for other departments and partly commercialize their exploitation through industry. One example is the Zero Emission Lab, which is currently developed in close connection with industrial partners DAF, TNO and Shell. Meanwhile, four of our labs (Future Fuels lab, Multiscale lab, MicroFab lab and Darcy Lab) have recently been promoted to the status of TU/e labs. Plans are currently developed to professionalize the labs further within the 'Gemini Project' to rebuild the ME facilities. An 'Equipment Fund' has been established as a university pilot in 2019 enabling sections to strategically save money for future upgrades of facilities. If evaluated positively in 2021, this plan will be taken up by the TU/e board and extended to the entire university. Within the department, the underlying strategy of the sections is evaluated and updated on an annual basis. A vision for the labs for each of the sections in the department is developed to facilitate both the departmental strategy w.r.t. the labs and as an underpinning of the equipment fund.

2.2 Strategy concerning future research

Novel scientific and industrial developments in the field of Mechanical Engineering urge our department to continuously re-evaluate its structure and scientific expertises in line with these developments. Some examples are the focus on extremely small scale (micro and nano) mechanics, which demands novel measurement equipment and (multiscale) modeling tools, but also micro/nano-scale design and fabrication techniques. Other examples are the current energy transition, novel additive manufacturing techniques and developments such as industry 4.0, factory-of-the-future, cyberphysical systems, and internet-of-things, and the shift towards more integrated design and control techniques for complex interconnected systems. The required interaction with other fields such as electrical engineering, computer science, physics, chemical engineering and data science is expected to increase, which lines up with the inherent multidisciplinary nature of the industrial and societal challenges of the near future.

The departmental board aims to make adequate decisions to strengthen research and education, to accommodate these future developments in our field. To assist the board with such important choices, the board asked a group of four professors (core team) to formulate an advice in the form of a vision document 'Mechanical Engineering beyond 2020' (see Appendix 8). The board exploits this vision document as a basis for future positions to create a sustainable section/department structure. The Argumentenfabriek, was approached to guide the process.

Over the period April–Sept. 2016, five brainstorm sessions were held with groups of stakeholders both from within and outside the department/university, including experts from industry. In each of the sessions, specific themes were discussed. The Argumentenfabriek, in consultation with our core team, summarized all main discussion points and emerging insights into so-called "maps". The maps follow a logical line of thought. The following maps are created: external trends and factors, internal trends and factors, vision on the role of the department, assessment framework and a long-list with relevant research themes. The results of this strategic analysis, including the obtained long-list of research fields were shared with the department staff during several follow-up sessions in 2017 and the department board incorporated the resulting advice in its future roadmap (see App. 8). Main conclusions and follow-up steps will be explained in the following. The following observations are standing out.

- A list of 8 **basic disciplines** of mechanical engineering was defined, referring to the eight areas of expertise that constitute the core of the mechanical engineering discipline: Mechanics, Dynamics, Thermodynamics, Fluid Mechanics, Materials Science, Systems and Control, Design and Construction and Manufacturing. All these should be represented substantially and visibly in the overall research program of the department, as well as in the educational curriculum.

- The art of mechanical engineering consists in the application of design, construction, manufacturing and control principles to mechanical, material and (thermo-)dynamical sciences.

- **Scientific excellence** is the core value of our research and it should be the basis of the department's strategy for the future. Valorization and industrial societal impact are very relevant as well, but should emerge from the excellent research. This is also the aspect that is valued most by our industrial partners. The department's structure should therefore be based on its scientific disciplines rather than (continuously changing) application areas.

- Connection with the **educational curriculum** is crucial: The department should warrant long-term excellence in education, by connecting to research in all 'basic disciplines' in mechanical engineering.

- **Multi-disciplinary collaboration** is highly relevant. This refers both to collaboration between disciplines within the department as well as with disciplines in other domains. Hence, research themes that hold potential for collaboration between (mechanical engineering) disciplines should have priority.

- **Design and Construction** was perceived by many of the session participants as an important differentiator for Mechanical Engineering, as compared to other engineering disciplines. The integrating and broad character of mechanical engineering is reflected especially in this basic discipline.

These points are in line with current vision of the department board and the existing structure of the department was created to form a solid **backbone** that is fit for the future. With this vision in mind a list of research themes that are important for the future have been identified:

- Thermo Fluids Engineering
  – Energy storage materials and systems

- Dynamical Systems Design
  – Autonomous, self-learning and self-correcting systems

- Computation and Experimental Mechanics
  – Predict and design of multifunctional materials from the smallest scale
  – Smart and responsive materials

Additionally, three positions related to (interdisciplinary) design were opened; one in each of the research clusters.

2.3 National and international research strategy

The national research strategy of the department is aligned with the Dutch university ecosystem. A good introduction to the basics of the system is provided in the 'A beginner's guide to Dutch academia'[9]. External funding of research is largely achieved through the national programs of the Dutch Science Foundation (NWO) and the Ministry of Economic Affairs and the international EU programs such as H2020.

In the so-called Research Universities Sector Agreement 2018 (the 'Sectorakkoord wo-2018'), the Dutch Minister of Education, Culture and Science and the publicly funded Research Universities in the Netherlands have set down their joint priorities for investments in the quality of research and education for the term of the present government. For research, these priorities are:

1. Creating clear research and education profiles per university;
2. Being at the international forefront in the field of open science;
3. Strengthening the social and societal impact of research;
4. Making more use of female talent in academia.

Various interlocking instruments were introduced to achieve these goals, of which the National Research Agenda ('Nationale Wetenschapsagenda', abbrev. NWA) and the Sector Plans ('sectorplannen') were the two most prominent ones. Additional resources for research were being made available as part of the coalition agreement via these instruments.

The NWA is a directional agenda, through which the government invests in broad-based consortia of universities, business sectors and others. The primary aim of the NWA program is to build bridges between various scientific fields, between different types of research (fundamental, applied, practice-oriented) and between national and international agendas.

The Sector Plans are used mainly to establish clear research and education profiles per university, and the government is using these in particular to invest in basic science and engineering research. The sector plans help to reinforce the basis of the research conducted at Dutch universities, whereby education and research and the contribution to social objectives are closely interwoven. The previously mentioned research vision of the board including the mentioned research themes is well-aligned with the sector plan. In July 2019, the Dutch government committed to an 8.5 M€/year for TU/e's Sector Plans for a period of five years. From these

9. The document 'A beginner's guide to Dutch academia' is available at `https://dejongeakademie.nl/shared/resources/documents/Abeginnersguide.pdf`.

funds almost 1.5 M€/year is for funding 10 new faculty positions at the ME department. After this 5 year period the positions are direct funded by the ministry.

2.4 Research positions in the department

To accommodate the increasing student inflow and expected increase in basic funding, the department board has the plan to appoint 30 new faculty in the near future. For this a long-list of research topics has been created in the *ME beyond 2020 strategy* (Appendix 8). The ME beyond 2020 core team was asked to prioritize this list and the same was done independently in a strategy session by the complete full professor's team in 2017. As the priorities are broadly shared, the board decided to focus the appointment of new faculty at first instance on the two top-themes selected from each main area and an additional one from the other categories. The selection is given below. Of these positions 10 are to be funded from the sector plans. Additionally, the department seeks to appoint one faculty for cross-disciplinary design research and one female faculty in each cluster.

In line with the TU/e board focus and design-funding strategy the Departmental Board has decided to facilitate the growth of DSD by creating positions in the area of autonomous systems and artificial intelligence and a new chair on robotics with additional faculty members.

Several additional positions are available for timely succession of faculty that is approaching retirement. The following list describes the positions available in the clusters (positions labeled succession are replacements of existing positions).

Computational and Experimental Mechanics (CEM)

1. Function integration in material systems and new materials (5 positions)
2. Cross-disciplinary design (1 assistant professor position)
3. Assistant professor (succession)
4. Female assistant professor (2 positions, one succession)

Dynamical Systems Design (DSD)

1. Modeling, sensing & control of autonomous systems and vehicles (5 positions)
2. Soft robotics (2 positions)
3. Autonomous systems / Artificial intelligence (3 positions)
4. Cross disciplinary design (1 assistant professor)
5. Construction (assistant professor, succession)
6. Nuclear fusion (assistant professor, succession)
7. Full professor (succession)
8. Female full professor Robotics (new section)

Thermo Fluids Engineering (TFE)

1. Multiphase reactive flows in dense aerosols and flow in porous media (5 pos.)
2. Cross disciplinary design (1 assistant professor)
3. Female assistant professor

2.5 Result of previous assessments

In the evaluation period 2007–2012, the department was evaluated at the departmental level and also at the level of the individual sections (then called groups). The department was evaluated across a number of aspects. The main conclusions (at the department level) including actions taken were as follows:

Institute level: The mission to conduct both industry-oriented and scientifically oriented work suits university of technology and is also ambitious. The topics of the research programs are generally well placed and fit into an industrial environment. The availability of common laboratories is a great achievement, reflecting the ambition of the department.

Quality and academic reputation: The quality of the research carried out in the ME department is impressive. The research makes significant contributions both to cutting edge topics as well as innovative applications of new concepts and methodologies. Many program leaders are internationally recognized as leaders in their field. The department is nationally leading and very visible.

Resources: The number of research staff (especially PhD students) has substantially increased over the review period. The slight decrease in direct funding is more than compensated for by the increase in the contract research as well as funds from research grants. Furthermore, the total funding has increased. There are research grants from ERC, at both the starting and advanced level, but grants at the intermediate level are missing. The experimental facilities are excellent, and sharing the facilities is a good way of using them.

> Due to increased workload the number of applications for personal grants did not rise significantly. The amount of personnel grants is a focal point for both the TU/e and the departmental board. The Departmental Board discusses opportunities with faculty members that are considered in a good position to apply for personal grants. Through the research support network candidates are supported in the application processes.

Productivity: The overall quantity and quality of the research carried out in the department is impressive. Most of the programs perform well above average normalized number of citations in the field. The number of patents should be increased; it is actually rather low and shows a steep decline over the years.

> The Departmental Board does not consider it the role of the department and its researchers to be heavily involved in acquiring patents. Because of the close research cooperation with industry, especially within Brainport Eindhoven, focus is on start-ups and take-up of innovations by industry partners.

Societal relevance: A department-wide strategy and support would help all programs to actively, structurally and coherently translate their scientific work into societally relevant output and impact.

> Some of the full professors in the department are very active in connecting research results with society (see the self-assessments of the sections for more details). The Eindhoven Engine was initiated and grown from within the ME department. The Departmental Board supports actively in areas of high societal relevance such as energy, artificial intelligence and robotics. Some of the laboratories of the department are opened up for use by other parties.

Strategy for the future: The main ambitions and goals for the future are well chosen. However, it feels that a clear strategy for personal development is lacking. A clear strategy for replacement, continuation or termination of important chairs should be put into place. The female proportion of the Faculty is well below 10%, and it strongly encourages the leadership to address this imbalance.

> In the previous section, the strategy of the department in these respects has been discussed at length. In Section 4.3, diversity, as one of the special SEP themes, is discussed.

PhD training and supervision: All PhD students should be embedded within a Graduate School. Also, the suggested transition to compulsory graduate programs to be set up for the next six years is regarded very favorably by the Committee. More information sharing between PhD students working on particular topics is desirable. The success rate of PhD students is rather impressive. The quality of the PhD theses was excellent.

> The department has a PhD council (Hora Est), shared with the department Biomedical Technology, in which PhD's participate. The Departmental Board has consultations with the PhD council to discuss relevant issues. The PhD students of the department are all embedded in the TU/e graduate school and almost all PhD students are member of one of the national research schools (see Section 4).

The assessment of the sections was impressive. On average, sections scored 4.5 out of 5. Three of the sections obtained the maximal score for all evaluated aspects.

3 Results

3.1 Publications and citations

Journal publications
The number of journal publications has increased by an average rate of almost 5% per year over the last period, leading to a total increase of 25% from 2013 to 2018. This indicates an increase in the number of journal publications per scientific staff member (fte) per year from 3.8 to 5.2. The number of PhD theses per scientific staff (fte) has been 1.3 per year on average over the evaluation period.

Table 4: Main categories of research output

Output	2013	2014	2015	2016	2017	2018
Refereed articles	240	247	227	278	312	296
Ref. conference papers	172	181	159	145	136	104
Book chapters	12	8	16	10	12	17
PhD theses	20	42	31	28	27	28
Total publications	**444**	**478**	**433**	**461**	**487**	**445**

Citation analysis
The field-weighted citation impact (FWCI) of the ME department as a whole over the period 2009–2018 is up to 50% above world average, FWCI=1.5, with a variation over the sections from 1.2 to 1.9. For the years 2013–2018, the FWCI indicator of the department's publications over a six year period varied between 1.5 and 1.7. The total impact of the research related to the FWCI multiplied with the total output increased significantly, due to the increase in the number of journal papers.

The percentage of the department's journal publications that appears in the top 10% journals is 41% and 2.6% is in the top 1% journals. The aim of the department is to reach 50% for the top 10% journals. The department aims to maximize visibility of its research in the top-journals by participating actively in the editorial boards.

A comparison of the FWCI of TU/e with a large number of reputable universities in the research area of Mechanical Engineering over the period 2009–2018 shows that, in the research area of Mechanical Engineering TU/e belongs to the top European universities. Universities with comparable impact are Imperial College London, Technical University of Denmark, Technical University of Munich and Delft University of Technology.

3.2 Scientific reputation

National and international scientific recognition of the department is related to the recognition and reputation of the faculty members, as shown by the large number of awards, memberships of editorial boards, listed in the self-assessment parts by the programs within the sections. The most relevant personal grants are:

- Simon Stevin Meester' Award[10]: de Goey 2010, Steinbuch 2016
- ERC Advanced Grant: Geers 2013, den Toonder 2018
- ERC Starting Grant: Deen 2010, Luttge 2011, Bellouard 2012, van de Burgt 2018
- Vici[11]: Heemels 2010
- Vidi[12]: Lefeber 2007, van Oijen 2009, Hoefnagels 2012, Oomen 2017
- Veni[13]: van Brummelen 2003, van Oijen 2003, van Dommelen 2006, Gaastra Nedea 2006, Hoefnagels 2008, Verhoosel 2011, Felici 2013, Oomen 2013.

3.3 Societal Relevance

To enhance the quality and maximize the societal impact of our research, the policy of the department is to focus strongly on the following areas.

Transfer of knowledge to society and industry Through the departments educational programs and research, highly educated people are delivered to society and industry. Most of our PhD students find employment in industry, and this is a very efficient route for knowledge transfer from academia to industry. Also, there are many artifacts that result from research, such as prototypes of machines and software that is transferred to industry.

Contribution to research on societal challenges Mechanical Engineering is actively involved in TU/e's Cross-Disciplinary Research Themes (CRTs) and Institutes. The CRTs provide an umbrella under which research sections from different departments are stimulated to cooperate on research themes that have been labeled as both scientifically challenging and societally relevant. The sections of ME participate in the following CRTs:

10. See the NWO site `https://www.nwo.nl/onderzoek-en-resultaten/programmas/simon+stevin-prijzen/simon+stevin+meester/` for more information. (The page is not available in English.)
11. See the NWO site `https://www.nwo.nl/en/funding/our-funding-instruments/nwo/innovational-research-incentives-scheme/vici/index.html`.
12. See the NWO site `https://www.nwo.nl/en/funding/our-funding-instruments/nwo/innovational-research-incentives-scheme/vidi/index.html`.
13. See the NWO site `https://www.nwo.nl/en/funding/our-funding-instruments/nwo/innovational-research-incentives-scheme/veni/index.html`.

- Smart materials & processes, embedded in the QNP institute
- Artificial Intelligence, embedded in the EAISI institute
- Bioengineering health, embedded in the ICMS institute
- Renewable energy, embedded in the IRES institute

A detailed account of the participation of the sections in the TU/e institutes has been provided in Section 1.6. Most of the PhD students work in areas related to these themes and institutes.

Enhance interaction between research and education The ME department has introduced three cross-disciplinary Master's programs: Automotive Technology (AT), Sustainable Energy (SET) and Systems & Control (S&C), and a specialization of the Mechanical Engineering Master's program called Manufacturing Systems Engineering (MSE). AT and SET fit well with the EAISI and IRES. A Bachelor's program in Automotive Engineering has also been started in 2011 by the Electrical Engineering department, with a strong contribution by ME to create a full educational curriculum in automotive technology. A two-year PDEng program in Automotive Systems Design has been launched by the Mathematics & Computer Science department, again in close collaboration with the ME department. Prof. Nijmeijer is director of the Graduate Program Automotive Systems (Master's AT and PDEng Automotive Systems Design (ASD)). Recently also a PDEng program Mechatronic System Design has been created under the ASD umbrella. The 4TU S&C Master's program has been introduced to educate students in the high-tech systems field, again in line with the goals of the industry within Brainport Eindhoven.

Collaboration with industry Mechanical Engineering actively participates in:

- *Brainport Eindhoven*, the local industrial clustering in the South-East Brabant region. The establishment of Brainport Eindhoven inspired Philips Electronics to establish the High-Tech Campus. Solliance (TNO, TU/e, Holst Center and ECN) and DIFFER (FOM institute for fundamental energy research of fusion and solar fuels which moved to the TU/e campus in 2015) are examples of joint initiatives that create opportunities to enhance collaborations with industry. 70% of all engineers in Brainport Eindhoven received a TU/e education.
- The *Leading Technological Institutes* in polymers (*DPI*) and materials (*M2i*), initiated through an industrial initiative and finally selected for relevance and past performance. Direct governmental funding of these LTI's ended, but has been replaced by competitive funding through HTSM funding calls by NWO-AES.
- Top Sectors such as *Energy*, *High-Tech Systems and Materials*, funding models introduced by the government to finance innovative research in collaboration with industry.
- *Impuls Programs*, a TU/e initiative that started in 2013, in which the university started new research with companies through the co-funding of PhD's. It is

clear that the research groups each have their own industrial networks, which are increasing in strength as shown by the solid contract and research funding (see Table 2).

Research valorization by spin-offs and student teams To enhance the impact of our research on society, the department is increasingly focusing on promoting research valorization. The ME Board therefore encourages the creation of an innovative departmental spirit in which

- innovations are developed,
- spin-off companies are initiated and supported, and
- from which creative student teams emerge.

The acquired strong valorization potential is apparent from the high level of collaborations with industry within the different groups, and this is also shown by the increase in external funding. Additionally, the department follows an active policy of initiating, accommodating and supporting spin-offs companies and student teams. This policy has been instrumental in acquiring strong external visibility, in triggering successes of student teams and in initiating a significant number of spin-off companies. The TU/e recently started Innovation Space where student teams can work and share their vision with industry. The department is a key contributor to the Eindhoven Engine.

Successful student teams:

1. Tech United[14], several times world champions in the Middle Size League of the RoboCup robot soccer competition and 2019 world champion in service robots;
2. URE[15], University Racing Eindhoven competes in the Formula Student competition, the world's largest engineering design competition;
3. Solar Team Eindhoven, world champions in the Michelin Cruiser Class of the World Solar Challenge 2013, 2015, 2017 and 2019;
4. InMotion works on improving electric refueling in order to achieve participation in the 24h race of Le Mans in 2023;
5. Team SOLID[16] develops a sustainable energy storage system with iron powder as circular energy carrier;
6. TU/ecomotive[17] developed Noah, a car that is sustainable in each phase of its life: production, use and recycling.

14. www.techunited.nl
15. www.universityracing.tue.nl
16. www.teamsolid.org
17. www.tuecomotive.nl

Spin-offs:

1. IME Technologies (dr. van Helvoirt MSc/R. Solberg MSc)
2. Sorama (dr. Scholte/Locht MSc MBA)
3. Progression Industry (dr. M. Boot)
4. Fistuca (J. Winkes MSc)
5. Heat Power (dr. H. Ouwerkerk)
6. Express Precision Engineering (dr. E. Bos/E. Treffers MSc)
7. Optimal Forming Solutions (dr. S. Boers)
8. Eindhoven Medical Robotics (A. Nayak/prof. M. Steinbuch)
9. Snocom (H. Arntz MSc)
10. Avular (A. Maas MSc)
11. Corellian (S. Kema MSc/M. Tullemans MSc)
12. Ratio Computer Aided Systems Engineering B.V. (dr. T. Wilschut))
13. Vertoro (dr.ir. M. Boot)
14. Preceyes (dr. G. Naus/dr. T. Meenink/M. Beelen MSc)
15. ZEnMO (drs. A. Hoekstra/P. Hogeveen/ prof. M. Steinbuch/prof. G. Verbong)
16. Microsure (Cau)

4 Standard Evaluation Protocol themes

4.1 PhD program Mechanical Engineering

In this subsection, the strategy of the department with respect to the PhD program Mechanical Engineering is detailed.

In the assessment period, 87% of the enrolled PhD students finished their PhD successfully, 10% of the students finished within 4 years, 74% within 5 years, and 83% within 6 years. 10% of the PhD student contracts have been discontinued, while 4% of them are still ongoing. These numbers do not include PhD students for which contracts were discontinued within the first year.[18] (See data Table 5.)

The average duration of the PhD period is 4 years and 4 months, only slightly above the nominal 4 years and well below the national average of 5 years[19]. Due to administrative procedures, the thesis defense is usually 3 months after the end

18. These are all PhD candidates conducting research with the primary aim of graduating, based on a 0.8–1.0 FTE contract. This includes PhD candidates with employee status (AiO/promovendi) and contract PhD candidates without employee status, receiving external funding or a university scholarship, who are conducting research under the authority of the research unit with the primary aim of graduating (Dutch: beurspromovendus).
19. Figure obtained from `https://www.vsnu.nl/en_GB/f_c_promovendi.html`.

Table 5: PhD Candidates

Enrollment				Graduation Pass Rates					
Started	Enrolment		Total	Graduated					
Year	M	F	T	<4	<5	<6	<7	Ongoing	Fail
2010	30	4	34	5	22	1	0	0	6
2011	33	5	38	4	25	4	2	0	3
2012	22	3	25	3	17	1	1	0	3
2013	32	2	34	1	23	4	2	3	1
2014	28	4	32	4	17	5	n.a	3	3
Total	**145**	**18**	**163**	**17**	**104**	**15**	**5**	**6**	**16**
	89%	11%	100%	10%	74%	83%	87%	4%	10%

of the 4-year PhD contract. Graduated in 4.3 years should therefore be interpreted as: the PhD work, including writing the thesis, is finished in 4 years. Accordingly, prior to the start of the defense the draft thesis is sent to the committee for approval (1 month), after which 2 months are required by the PhD regulations (approval by the Doctorate Board; thesis printing etc.).

- Only a small fraction of the enrolled PhD students have been admitted on the basis of an external scholarship (e.g. the China Scholarship Council). The majority of the students have been employed with a regular PhD salary at the university or on the payroll of NWO domain Science or M2i.
- PhD students write a progress report after their first year, which is followed by a go/no go decision with respect to the following 3 years.

PhD students allocate 15–30 EC of their time to further education and professional development. The university offers a set of personal development (PROOF) courses[20]. PhD students gain experience in giving talks and presenting posters at national meetings and workshops organized by the local research groups and research schools, and at the international level by presenting at conferences.

Most science/engineering based PhD courses are organized by the (national) research schools, offering course packages from 20–30 EC. Almost all PhD students

20. E.g. Dutch, writing articles in English, career development etc. See `https://www.tue.nl/en/storage/careers/development-and-career/scientific-personnel/phd-and-postdoc/providing-opportunities-for-phd-students-4tu/` for more information.

in the department are embedded within such a school. The research schools serve as a common platform for the development of PhD courses (which are normally given by professors of all participating universities and are accessible to all PhD students). Each research school has its own regulations for participation in and size of the education and professional development activities. The schools also support the international profile of the research area. An additional benefit of this system with national research schools is that it stimulates cross-university collaborations of both the involved PhD students and the faculty supervising them.

The department participates in the following research schools:

- Engineering Mechanics (abbrev. EM; commissioner: Department of Mechanical Engineering TU/e). See appendix (page 109) for more on this.
- JM Burgerscentrum (JMBC, fluid mechanics)
- Dutch Institute of Systems and Control (DISC)
- BETA Research School for Operations Management and Logistics
- Eindhoven Polymer Laboratories (local research school; commissioner: Department of Mechanical Engineering, TU/e)

Most PhD students are affiliated with one of the first three national interuniversity research schools. The department of Mechanical Engineering at TU/e acts as commissioner of EM (page 109). The research schools EM, JMBC and DISC have a longstanding tradition of providing high-level domain-specific training for PhD students. Note that several of the PhD courses are organized with international participation of lecturers and PhD students. Existing successful course programs (e.g. CISM) are also integrated in the course package to obtain a certificate.

In addition, the research schools serve as a platform for PhD students to meet peers from other universities and for scientific staff to exchange ideas and information. In former years, all graduate schools were accredited by the Royal Netherlands Academy of Arts and Sciences (KNAW) according to a hexennial cyclic review-and-accreditation procedure. This accreditation system was discontinued in 2014.

At the end of 2016, the TU/e Executive Board finalized its Position Paper 'Training and development of PhD candidates at the TU/e Graduate School' (see Appendix 12).The Position Paper contained the vision of the TU/e Graduate School on PhD training and development and, in particular, articulated measures to strengthen the (existing) safety net for TU/e PhD students, both on payroll and not on payroll. This was deemed necessary as PhD candidates may experience considerable pressure in their work (due to a variety of factors). The safety net includes all facilities within TU/e where PhD candidates can get support in case of problems during their PhD trajectory. This includes instruments to prevent problems and issues, and support PhD candidates can turn to in such cases.

Following the Position Paper, a number of steps and follow-up actions were (c.q. are now being) taken. All of these steps take place under the supervision of the TU/e Graduate School Dean. As part of the implementation project, a project group 'safety net PhD candidates' was installed as well. The following measures were/are taken:

- to provide clear and uniform information from the start of the PhD trajectory;
- to appoint a PhD contact person close to the PhD candidates;
- to provide a PhD mentor on demand;
- to appoint a PhD psychologist at the university level;
- to provide more support for supervisors;
- to permanently promote cooperation within the safety net.

In the coming period, on a university level, a tracking system Hora Finita is rolled out that supports PhD students, their supervisors and the department in monitoring and assessing the status of a PhD trajectory.

4.2 Research integrity

Codes of Conduct
The department follows TU/e in safeguarding a number of core values. Scientific independence and integrity of scientific staff are key priorities, specifically with respect to transparency and integrity in building and maintaining business and industry relationships. This is why at TU/e we have committed ourselves to codes of conduct.

The department adheres both to the Netherlands Code of Conduct for Research Integrity[21] and to the TU/e Code of Conduct[22], which is a comprehensive version of the (former) Netherlands Code of Conduct for Academic Practice that takes into account the specific characteristics of scientific activities at a university of technology.

Group leaders and supervisors have the responsibility to create an open atmosphere at work, in group meetings and individual progress meetings, so as to make discussions on integrity and ethics more comfortable, stimulating an open-minded way of working.

21. https://www.vsnu.nl/en_GB/research-integrity
22. The Code may be found https://www.tue.nl/en/our-university/about-the-university/integrity/codes-of-conduct/.

Faculty members are also held responsible vis-à-vis the integrity codes in a formal sense. Specifically, at their start, new faculty members, PhD students, PDEng trainees, MSc students and guests are required to sign the TU/e Code of Conduct, which is attached to the employment/guest contract. At the end of their research or design project, PhD students and PDEng trainees are obliged to sign a declaration that their thesis or report was written in compliance, again, with the TU/e Code of Conduct.

At the university level, contact persons are available for TU/e staff and students who experience (or suspect) misconduct, inappropriate behavior or conflicts, and need help in reaching a solution or submitting a formal complaint.

Data Handling and Storage Management
Laboratory journals form an integral part of data and results management and remain in the group after completion of each (BSc, MSc, PhD or Postdoc) project. Data and metadata from experiments are logged in laboratory journals according to commonly accepted methodologies in the field. Collected data/metadata typically include date, creator, relevant experimental conditions, instrumental analysis equipment and relevant instrument settings, etc. The program leader is responsible for the management of the research data of the research group. Data have to be stored in an accessible form and as long as required for intersubjective testing and in accordance with the rules of the funding agencies.

Our strategy is to store all data that is needed to replicate or reproduce published scientific results. For software-based data, this mainly implies all scripts and source code used to generate results.

The expanding volume of research data has prompted the academic staff to look for adequate storage facilities. TU/e's Information Expertise Center (IEC) provides library and archive services for the TU/e community and is the university information and research center for data management. IEC is conducting research into new methods for storage and management of raw and processed data of scientific research, in close cooperation with academic staff and the 4TU.Center for Research Data. The diversity and volume of the collected data require deposit facilities that are specific for the research area and experimental set-up.

From 2020 onwards, the department will make a yearly inventory of the needs of the research staff with respect to research data management in a broad sense, which will provide the board with sufficient information to act accordingly. Both current practice and expected future needs of the sections are discussed and if necessary the board may take measures to assure that the sections are supported by appropriate infrastructure and regulations.

Open access

From April 2015 onwards, authors at TU/e register all peer-reviewed journal articles and submit the final, accepted authors' versions for inclusion in the TU/e Repository. All of the open-access criteria for scientific publications the Dutch national government and the EU's Horizon 2020 program have set, are met as a result. TU/e's Information Expertise Center (IEC) verifies copyrights, and makes articles available through Open Access as soon as this may be done legally. TU/e provides help when questions arise, via TU/e's 'Open Access Coach' (link).

Ancillary activities

In general, TU/e takes a positive attitude towards its employees executing ancillary activities. Ancillary activities, either executed in association with regular activities or not, can encourage a positive interaction between TU/e and its social and industrial environment. Ancillary activities may, however, conflict with the interests of TU/e. For that reason, TU/e adheres to openness in respect of the discussion of ancillary activities between employees and supervisors. In order to be fully transparent on this point, all ancillary activities of TU/e's staff are listed on their personal web-pages, and they are held responsible for keeping their data up-to-date. Details are given in the 'TU/e ancillary activities' regulations (2007)[23].

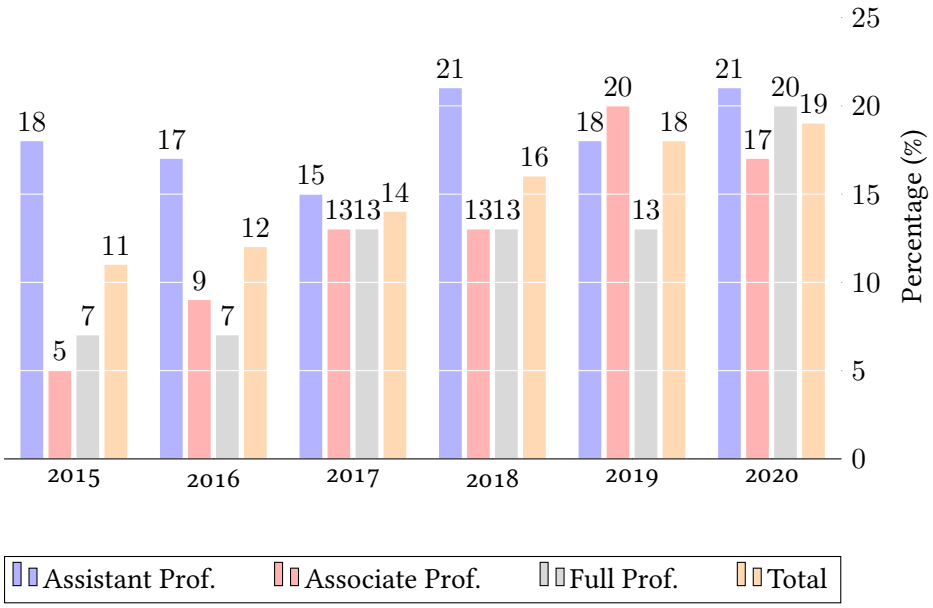
4.3 Cultural diversity and gender balance

Diversity is of key importance for being an excellent, globally oriented and internationally oriented organization, which reflects the diverse society at large as much as possible. The university and department stimulate appointment of staff and attract students from all corners of society without any borders between countries, races, cultures and gender. TU/e implements a broadly supported modern gender and diversity strategy striving for a balanced international staff to support an overall inclusive and international environment with at least 1/3 of its students to be international by 2023, and 25% of its research staff to be female by 2023. Obtaining a better gender balance is our most pressing issue at present.

In our educational programs the fraction of female students is limited. For the bachelor and master Mechanical Engineering the fraction of female students is 9% and 7%, respectively. For the inter-departmental masters the fractions are 5% for AT, 19% for SET and 10% for S&C. For the different categories of faculty, the percentages of women over the years are provided in Table 6. Also the projected percentages for the years to come are provided in that table.

23. See `https://www.tue.nl/en/our-university/about-the-university/integrity/ancillary-activities-regulations/`.

Table 6: Female faculty participation



- Specific measures are to train staff in recognizing gender and cultural bias and to advertise positions in an open manner engaging a broad range of candidates.
- For each male candidate that appears in front of a recruitment committee minimally one female candidate must be proposed as well. The department experiences that suitable female candidates have many options for academic positions. Therefore the board aims for a share of female appointments of at least 35%.
- On Sept. 1, 2019 the TU/e board introduced the Irène Curie Fellowship program (2019–2024), with the aim to boost the recruitment of female scientists. TU/e will open vacancies for assistant, associate and full professor exclusively for female talent during the first six months of recruitment. The starting package for these fellowships has an additional 100 k€.
- 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 Eindhoven area; the recruitment organization will also actively connect to companies like ASML, Philips, NXP, VDL and DAF.
- A newly introduced recruitment support organization helps the departments in the hiring process and safeguards, together with the diversity officer, gender and diversity issues.

Still, most of the staff is of Dutch origin due to historical reasons and because most of the student inflow is Dutch. The inflow of non-Dutch students has increased

significantly over the last years, due to the Masters SET, S&C and AT in which the majority is non-Dutch. The current percentage of non-Dutch Master students is 25%, while the percentage of non-Dutch PhD students is 50%. In 2019, the Bachelor Mechanical Engineering has switched from Dutch to English language, opening the possibility to attract more non-Dutch Bachelor students. The department's goal is to reach a 33% amount of non-Dutch students and staff in the future.

The main departmental focus is gender bias. Our current ratio of female faculty members is 18%, approaching the goal of 20% in 2020. Following university policy, the appointment committees of professors always contain at least 2 female professors. In the recruitment of the last 3 professor positions, the appointment committee was able to initially identify between 50 and 100 women in each case. Still, in the case of the MS and MRF sections, a male candidate was appointed in the end. Main reason is that it appears to be very difficult to find excellent female candidates who finally accept the offer given to them.

The department expects a rise in the amount of female faculty members to 20% following the strategy described below.

- The board expects that the few female assistant professors will be promoted to associate professors between 2019 and 2023.
- Part-time professor positions are currently mainly financed by the research groups or by industry. The board has decided to finance and appoint 1 female assistant professor in each of the 3 clusters starting from 2017. Groups are requested to look for talent and submit proposals. Part-time positions are a possibility in case a good candidate is found.

Appendices

1 Control Systems Technology

Program leader	Prof.dr.ir. M. Steinbuch	0.6
Full professors	Prof.dr.ir. W.P.M.H. Heemels	1.0
	Prof.dr. M.R. de Baar	0.2
	Prof.dr. H.P.J. Bruyninckx	0.2
	Prof.dr. W. J. Fokkink	0.1
	Prof.dr.ir. J.P.M.B. Vermeulen	0.2
	Prof.dr.ir. F.P.T. Willems	0.2
	Prof.dr. A.M.L. Kappers	0.2
Associate professors	Dr.ir. L.F.P. Etman	1.0
	Dr.ir. M. Heertjes	0.1
	Dr.ir. A.G. de Jager	1.0
	Dr.ir. M.J.G. van de Molengraft	1.0
	Dr.ir. M.A. Reniers	1.0
	Dr.ir. T. Hofman	1.0
	Dr.ir. T.A.E. Oomen	1.0
Assistant professors	Dr.ir. D.A. van Beek	0.6
	Dr.ir. J. Elfring	0.2
	dr.ir. J. van Eekelen	0.2
	Dr. D.J. Guerreiro Tomé Antunes	1.0
	Dr.ir. T.A.C. van Keulen	0.2
	Dr.ir. J.M. van de Mortel-Fronczak	0.8
	Dr.ir. E. Silvas	0.2
	Dr.ir. G. Witvoet	0.2

1.1 Mission and vision

The major societal needs and challenges require significant contributions by engineering sciences in general and systems theory, control engineering and mechatronics in particular. Our Control Systems Technology (CST) section is at the heart of these developments with its mission to carry out high-level research to create new methods and tools in the area of systems theory, systems and control engineering and mechatronics design. The research focuses on understanding the fundamental system properties that determine the performance of mechanical engineering systems, and exploiting this knowledge for the design of the high-tech systems of the future. In particular, the research program concentrates on performance-driven control and systems engineering and design, and develops

robust and data-driven control theory, hybrid and networked systems theory, optimization techniques and mechanical design principles aimed at motion systems, robotics, vehicle powertrains, mobility and agriculture systems, and plasma fusion. The strategic focuses on applications in High-Tech Systems, AgroFood, Health (robotics for care and cure), Smart Mobility (connected cars and clean vehicles) and Energy (fusion plasmas) create natural links with the Brainport region Eindhoven and far beyond.

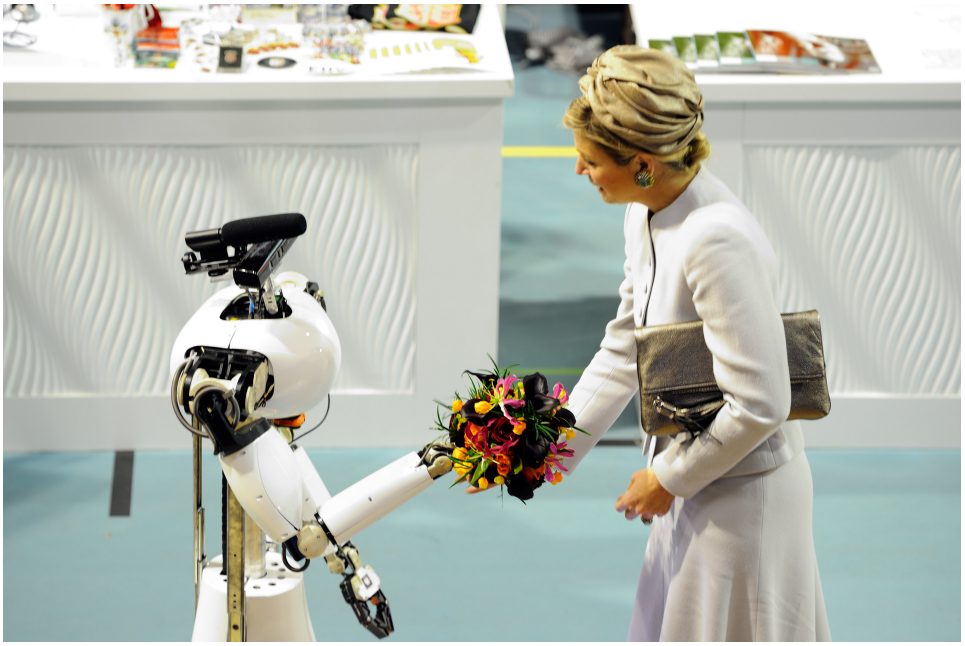
To realize our mission we focus to have an internationally leading role in research in our areas, combining this with inspiring education for our students and actively supporting and initiating valorization through spin-off companies as well as direct co-operation with industry.

1.2 Research themes

The research is structured in 5 subprograms.

Model-based Control, Data-based Learning, Identification and Design of Motion Systems
New techniques based on identification, data-based learning (e.g., iterative learning control) and feedback control are being developed to accommodate reference-induced errors. The development of design and construction principles for the creation of high-tech systems focuses on the research question of how to design for stiffness with high reproducibility and manufacturability, and sometimes for low cost and low thermal sensitivity. Applications in the high-tech systems industry are abundant (ASML, Philips, Océ, Thermo-Fisher, CCM-Sioux, VDL-ETG, various SMEs).

Hybrid and Networked Control Systems and Systems Engineering
Inspired by highly relevant applications in networked systems ('systems of systems' and multi-agent systems) including intelligent traffic systems, smart manufacturing and industrial automation systems (Industry 4.0 and Internet of Things), automotive and logistic systems and infrastructure (waterways), foundations have been developed for distributed control of physical systems over digital communication networks, resource-aware (event-triggered) control, as well as structured supervisory control and system design methods. The methods are being developed in close co-operation with leading industries such as NXP, TNO Automotive, ASML, Technolution, FEI, Honeywell, Ford, RWS etc.



Queen Maxima visiting the TU/e RoboCup ceremony. (Picture Bart van Overbeeke).

Robotics

The Robotics subprogram aims to advance the state-of-the-art robotics in health-related and AgroFood applications. To enable robots to perform a wide variety of household tasks we are investigating the cognitive abilities of domestic service robots. For both the domestic (care) as well as the medical (cure) application field our section realises world-class design of high-performance robots (MidSize Turtle, Amigo, Sofie, PRECEYES, Microsure, MRT, etc). In this field we have broad co-operations with medical academic hospitals and SME industries, and founded various start-ups (PRECEYES, Microsure, MRT, etc). We initiated various new research projects in the field of precision agriculture and robotics for AgroFood in a strong co-operation with Wageningen (WUR).

Automotive Powertrains and Smart Mobility

Our research is heading towards integrated powertrain control, in which energy and emissions management of the overall powertrain is fully integrated. Moreover, the research on new high-tech powertrain concepts for hybrid and electrical drive trains with different applications ranging from ships, tugs (maritime) towards cars and trucks (automotive) is resulting in new innovations. To derive an efficient integrated system-level design method, the theoretical concepts of computational design synthesis (discrete topology design formulated), multidisciplinary optimization and optimal control methods are adopted for complex dynamical engineering systems. The methods are being implemented at DAF Trucks,

Punch Powertrain, TNO Automotive, Bosch Transmissions and other industrial partners. In recent years we also expanded our interest towards automated transportation systems, e.g., based on automated guided vehicles, to solve current mobility issues.

Control of fusion plasmas
Our main focus is on the control of magneto-hydrodynamic instabilities and the control of distribution of the current density, temperature and particle distribution in the plasma, using new sensor designs, system identification and control-oriented modeling. The unique properties of the control-oriented plasma simulation code RAPTOR has allowed applications in state reconstruction, prediction and feedback controller design for the plasma density profiles. The developed algorithms have been implemented on various experimental fusion devices (tokamaks) in Europe.

1.3 Major accomplishments in the evaluation period

An important recognition of our performance is the excellence rating [5555] in the previous two (!) research assessments. Furthermore, we are proud of the prestigious individual VICI grant for Heemels (2011), the VIDI grant for Oomen (2017) and the two VENI grants for Oomen and Felici (2013), as well as the IEEE Fellowship for Heemels (2016) and Steinbuch (2019), the ITER fellowship for Felici (2016), the STW Simon Stevin Meester Award (2016) for Steinbuch (who was also appointed as Distinguished University Professor in 2013) and the various awards (see Appendix). Moreover, we became world champion with our soccer robot team in 2012, 2014 2016, 2018 and 2019! The plenary lectures given at the SYSID 2012, MSC2013 and the ACC 2013 by Steinbuch, the keynotes by Heemels at the leading conferences NMPC 2012 and 2015, ECC 2014, CDC 2018, NECSYS 2019, etc., and Heemels' chairmanship of the IFAC Technical Committee of Networked Systems, etc., all further confirm the international visibility of our section and research. The first human trials (2016) with our unique eye surgical robot PRECEYES done by Oxford University Hospital and broadcasted on BBC1 news, and the EURetina award for the device, confirms our leadership in high precision medical robotic devices. In 2016 we also founded the second company Microsure BV for further developing our research results in the field of robotics for microsurgery.

Our scientific highlights are:

1. *Model-based Control, Data-based learning, Identification and Design of Motion Systems:* the achievement of developing a method for identification of highly complex system dynamics with very robust numerical conditioning, a new method for learning control for varying setpoints, and a new method of de-

signing with high damping materials special components for high precision motion systems.

2. *Hybrid and Networked Control Systems and Systems Engineering:* In the field of supervisory control of concurrent discrete-event and hybrid systems, the section has developed novel methods and tooling for specification, analysis, synthesis and implementation of supervisory controllers, which create promising opportunities for industry-scale applications. New analysis and design methods are proposed for resource-aware feedback control, which received worldwide recognition as underlined by various awards and keynote lectures at leading conferences.

3. *Robotics:* we initiated the EU RoboEarth project on developing a common database and language for robots. The project was very successful, and lead to a further recognition of our leadership in the domain. The Preceyes robot system was applied to humans successfully, as a world's first. The Microsure robot was developed with great potential and societal impact. We started/participated in many robotic initiatives: H2020 EurEyeCase, ARTEMIS Joint Undertaking: R3COP, R5COP, etc.

4. *Automotive Powertrains and Smart Mobility:* a new computational design approach for automated discrete topology generation of dynamical systems from system to component level based on constraint satisfaction programming as part of a multidisciplinary optimization framework, new automated modeling techniques for arbitrary electric and hybrid powertrains, and new co-design methods for combined control, actuation and transmission design. Development of a systematic design method for air path control for heavy-duty diesel engine. The potential is demonstrated on a state-of-the-art multi-cylinder engine. Currently, this methodology is applied within DAF.

5. *Control of fusion plasmas:* demonstration of model-based predictive control of current density and pressure in fusion plasma experiments (MPC) . Implementation of model-based dynamic state observers for reconstructing the plasma state from several diagnostics. Efficient real-time calculation of the optimal allocation of a restricted set of actuators for multiple control tasks for the ITER tokamak, using mixed-integer quadratic programming. Demonstration of vertical position control using optical sensors and of locking control of the sawtooth instability in TCV tokamak plasmas.

1.4 Prospects

The CST section is one of the co-founding sections of the TU/e High Tech Systems Center (HTSC). This brings new directions and collaborations within mechanical engineering, and with physics, computer science and electrical engineering. We foresee major scientific contributions with societal impact on the boundaries of

these disciplines. Examples include a new systems design approach for additive manufacturing equipment, as well as for the design of high-tech machines for photonics (with EE) and vacuum applications (with physics). The impact of software and AI algorithms on manufacturing, systems engineering and robotics connects seamlessly to our experience in these fields. Combining this with the establishment of the Eindhoven Artificial Intelligence Systems Institute (EAISI), strongly tied to HTSC, brings grand potential for the future. The explosion of real-time available data enables our section to strengthen our recognized globally leading position even further in advanced motion systems and hybrid and networked control by integrating model- and data-based control approaches in which we have invested significantly the last years. Our knowledge of optimization theory enables us to support the major questions of co-design and systems engineering for highly complex systems. Finally, our robotics leadership in world modeling will have a great impact for autonomous systems in areas such as logistic systems, transportation and mobility systems, and our leadership in precision robotics for surgery will both grow on the side of valorization but will also stimulate new scientific challenges in micro surgery research.

The challenge for the section is to accommodate the enlargement over the past years , and to maintain and strengthen our structure and working culture aimed at scientific quality at excellence level, while still enabling the outstanding relation we have with the industry with enormous societal impact. It also means we have to implement a strategy of limiting our educational effort to our current (maximum) level. The planned start of young new staff in 2019–2020 will be beneficial in this respect.

1.5 Publications, prizes and awards

Key publications in evaluation period

- T. Oomen, R. van Herpen, S. Quist, M. van de Wal, O. Bosgra, and M. Steinbuch, *Connecting system identification and robust control for next-generation motion control of a wafer stage*, IEEE Transactions on Control Systems Technology, 22(1):102–118, 2014. 2015 IEEE Transactions on Control Systems Technology Outstanding Paper Award
- D. Antunes, W. Heemels, *Rollout event-triggered control: beyond periodic control performance*, IEEE Transactions on Automatic Control 59(12), 3296-3311, 2014
- E. Maljaars, F. Felici, M. R. de Baar, J. van Dongen, G. M. D. Hogeweij, P. J. M. Geelen, and M. Steinbuch, *Control of the tokamak safety factor profile with time-varying constraints using MPC*, Nucl. Fusion, vol. 55, no. 2, p. 23001, 2015.
- E. Silvas, T. Hofman, N. Murgovski, P. Etman, M. Steinbuch, *Review of Optimization Strategies for System-Level Design in Hybrid Electric Vehicles*, IEEE Trans-

actions on Vehicular Technology, 66(1):57-70, 2017 Feru, E., Murgovski, N., de Jager, A.G. & Willems, F.P.T. (2016), *Supervisory control of a heavy-duty diesel engine with an electrified waste heat recovery system*, Control Engineering Practice, 54, 190–201.

- W Heemels, MCF Donkers, AR Teel, *Periodic event-triggered control for linear systems*, IEEE Transactions on Automatic Control 58 (4), 847-861 2013
- T. van Keulen, J. Gillot, B. de Jager, M. Steinbuch, *Solution for state constrained optimal control problems applied to power split control for hybrid vehicles*, Automatica, Vol. 50 (1), pp. 187-192, (2014).
- A.C. van Hulst, M.A. Reniers, and W.J. Fokkink, *Maximal Synthesis for Hennessy-Milner Logic*, ACM Transactions on Embedded Comp. Systems, 14(1):1-21 (2015)

Scientific awards and scholarly prizes

- VENI (Felici 2013; Oomen 2013), VIDI Oomen (2017), VICI Heemels (2011).
- In top 25 of New Scientist 'Wetenschapstalent' (composed of young researchers (born after 1980) in all scientific disciplines, working in the Netherlands and Flanders): Oomen (2016)
- IEEE Fellowships: Heemels (2016), Steinbuch (2019)
- Honorary Doctorate Univ. of Southern Denmark, Odense: Bruyninckx (2014)
- *Optimal Cost-NOx Trade-Off in Diesel Engines by Integrated Emission Management* written by J. van Schijndel, M.C.F. Donkers, F.P.T. Willems and W.P.M.H. Heemels has won the 'Student Best Paper Award' at the 35th FISITA Congress 2014. Willems, Heemels (2014)
- 2016: Young Talent Tata Steel Award (5000 euro) for MSC Thesis Yuri Steinbuch entitled *Sequential Optimal and Predictive Control for Cascaded Systems with Applications to Quadcopters* (student of Heemels).
- 2015: Unilever Research Award for MSC Thesis Stefan Heijmans on spatially invariant systems with networked communication (student of Heemels).
- First place Benchmark competition 14th European Control Conference (ECC 2015), 15-17 July 2015, Linz, Austria *Towards constrained optimal control of spark-ignition engines*: Emmanuel Feru, Xi Luo (2015)
- 2nd Place at the Plug-in Hybrid Electric Vehicle Benchmark Competition with a solution to optimally control a Chevrolet Volt, for Silvas and Hofman. This was organized at the IFAC Workshop on Engine and Powertrain Control, Simulation and Modeling (E-COSM 12), held in Rueil-Malmaison, France, in October 2012. It resulted in a journal article in 2014.

- Best paper award: Elfring, J., Jansen, S.E.P., Molengraft, van de, M.J.G. & Steinbuch, M. (2013). *Active object search exploiting probabilistic object–object relations*. Proceedings of the RoboCup 2013 Symposium, 26-30 June 2013, Eindhoven, The Netherlands Eindhoven: Jos Elfring, van de Molengraft (2013)
- Kivi Academy Society Award: Steinbuch (2015)

2 Dynamics and Control

Program leader	Prof.dr. H. Nijmeijer	1.0
Full professors	Prof.dr.ir. I.J.B.F. Adan	0.2
	Prof.dr.ir. I. Lopez Arteaga	0.9
	Prof.dr. H. Nijmeijer	1
	Prof.dr.ir. N. van de Wouw[24]	0.8
	Prof.dr. A.M.L. Kappers	0.2
	Prof.dr.ir. P. W.A. Zegelaar	0.2
	Prof.dr. H.J. Zwart	0.2
Associate professors	Dr.ir. I.J.M. Besselink	1.0
	Dr.ir. R.H.B. Fey	1.0
	Dr.ir. P.C.J.N. Rosielle	0.5
	Dr.ir. M.F. Heertjes	0.1
	Dr.ir.H. Sadeghian	0.2
Assistant professors	Dr.ir. A.A.J. Lefeber	1.0
	Dr. A.Y. Pogromsky	1.0
	Dr. A. Saccon	1

2.1 Mission and vision

Our mission is to conduct high-level research in the area of Dynamics and Control, with the emphasis on modeling, analysis and control of mechanical, mechatronic and multi-physics systems. Nonlinear dynamics and control, acoustics and robotics are among the focal areas of the group. Fundamental research is combined with numerical tools and supported by dedicated laboratory experiments and/or direct implementation in industry ('Industry as Laboratory'). Teaching at undergraduate and graduate levels, in the spirit of von Humboldt, is a key integral part of the mission of the group, to provide students with state-of-the-art knowledge of and skills in Dynamics and Control, certainly in the high-tech region that Eindhoven represents. This is a key scientific field which is relevant to many advanced application areas, such as, .e.g., smart mobility, energy, high-tech systems, manufacturing and health. On the one hand, requirements for the efficiency, accuracy and reliability of these systems are constantly increasing. On the other hand, in an increasing complex world, these systems become more and more connected to both other technological systems and people. These developments urge the need for both model-based and data-based tools for the robust and agile

24. Period 01-04-2015 to 31-12-2018, otherwise 1 fte

design of smart systems, which makes it necessary to unravel detailed dynamic models for analysis, to develop advanced numerical tools for simulation, to develop automation strategies and to provide an experimental proof-of-principle. In the context of the above, the ultimate objectives are:

- to carry out world-class research in the field of dynamics and control of complex systems, with a focus on mechanical and mechatronic, high-tech applications,
- to combine this with excellent teaching at Bachelor's, Master's and PDEng levels in mechanical engineering, tailored to both the scientific state-of-the-art and the industrial state-of-practice,
- and to address societal, industrial and valorization aspects of the research. It is our vision that fulfilling our objectives makes key contributions to general research challenges, but particularly to the technological and societal challenges that we face from both industry and society.

2.2 Research themes

The Dynamics and Control group focuses on the following research themes:

1. *Nonlinear dynamics of mechanical systems:* The analytical, numerical and experimental study of complex (nonlinear) systems, such as mechanical systems experiencing friction or impact phenomena and/or with a large number of degrees of freedom, are key activities in this sub-theme. Both first-principle and data-based modeling and model complexity reduction of complex (possibly multi-physics) systems serve as a basis for this goal.

2. *(Structural) acoustics and noise control:* addresses (i) modeling and experimental techniques to understand surface roughness-related sound generation due in rolling contacts in ground transportation systems, (ii) Lightweight (meta)-materials to optimize sound absorption and transmission, (iii) Smart monitoring and diagnostics by means of acoustic images and artificial intelligence.

3. *Nonlinear control, synchronization and robotics:* In the nonlinear control area, the emphasis is on problems related to (i) stability, stabilization and performance of nonlinear/hybrid control systems; (ii) synchronization/coordination of networked (mechanical) systems; (iii) networked control of cyberphysical systems, and (iv) impact-aware robotics, e.g., for logistics applications.

4. *Vehicle dynamics, tire dynamics and control:* The research focus is on improved tire dynamics modeling (beyond the standard tire models), modeling analysis and control of articulated (long and heavy) vehicles (LZVs), building and developing an electric research vehicle for energy-efficient aspects in electric vehicles. A subject that is intimately linked to the previous subject is the theme

of 'Connected Cars', in which cooperative and autonomous driving is investigated to support improved traffic flow, increased fuel efficiency and reduced environmental footprint, both on highways and in urban scenarios.

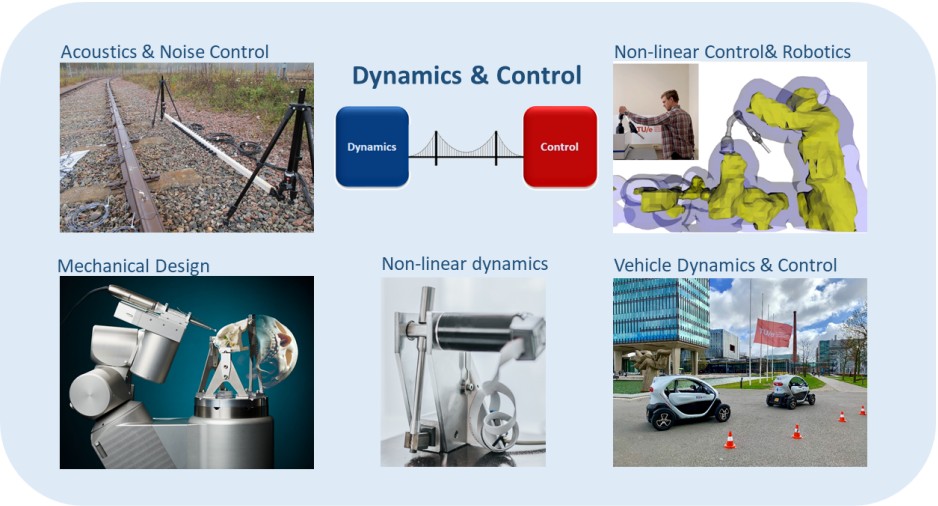
5. *Mechanical design:* The Constructions and Mechanisms subgroup (jointly with the Control Systems Technology group) focuses on a range of research questions in mechanical design. Design projects on position accuracy form a substantial part of the group's work.-

The above research themes provide a coherent representation of state-of-the-art research in the field and, although listed as separate lines, there are often cross-links between the themes.

2.3 Major accomplishments in the evaluation period

The Dynamics & Control section is internationally and nationally recognized as shown by the numerous academic and scientific achievements, collaborations and contributions of its members. Among other achievements we highlight:

- *Our (part-time and visiting) professorships at other institutions in the Netherlands and abroad:* van de Wouw- Delft University of Technology, The Netherlands (2015–2019) and University of Minnesota, U.S.A. (2014-present), Progromsky- ITMO University, Russia (2013-present), Lopez Arteaga- KTH Royal Institute of Technology, Sweden (2011-present).
- *Our (advisory) appointments in service of the (scientific) community:* Nijmeijer- Scientific Director DISC, The Netherlands (2015-present), Board member International Physics and Control Society (IPACS) (2015–present), Honary knight of the Golden Feedback Loop (NTNU, 2011) Panel Member VolkswagenStiftung, (2015–present) and Council Member IFAC (International Federation of Automatic Control), (2012–2014), chair Advisory board Sorama (since 2009), Corresponding Member of the Mexican Academy of Sciences (2016), Scientific Director and chairman Science board NOMI (Nano-Opto-Mechatronics Instrumentation, a collaboration between TNO and TU/e), Associate fellow ICMS (Institute of Complex Molecular Systems). Lopez Arteaga- Advisory board member Sorama BV (2010–2014), Vice-director Odqvist Laboratory for Experimental Mechanics, Sweden (2013–2016), Elected member Board of Directors IIAV (International Institute of Acoustics and Vibrations (2012–2016), Board Member NAG (Dutch Acoustic Society) (2014–2019) and member International Scientific Advisory Board of Linköping Center for Sensor Informatics and Control-LINK-SIC (2018-present).
- *Our editorial and advisory assignments in journals and international conferences, for example:* Fey- Associate Editor SAGE Journal of Vibration and Control (2012-



present), Lopez Arteaga- Subject Editor Journal of Sound and Vibration (2011–present) and scientific committee of NOVEM 2018 in Ibiza, Spain, Nijmeijer- Editor Communications in Nonlinear Science and Numerical Simulation, Corresponding editor SIAM Journal on Control and Optimization, Editorial board member of International Journal of Bifurcation and Chaos in Applied Sciences and Engineering, International Journal of Robust and Nonlinear Control, International Journal of Control and Nonlinear Dynamics (2014-present), Pogromsky, Nijmeijer, Lefeber - Organization of the 12th IFAC International Workshop on Adaptation and Learning in Control and Signal Processing (ALCOSP 2016) and 6th IFAC International Workshop on Periodic Systems and Control (PSYCO 2016) in Eindhoven, June 2016, Lefeber, Oogromsky and Nijmeijer, Organization of 5th IFAC Chaos Symposiumv, November 2017, Eindhoven, van de Wouw- Associate editor of the IEEE Transactions on Control Systems Technology (2014-now) and the IFAC journal Automatica (2012–2019), Organization of the 3rd International Colloquium on Nonlinear Dynamics and Control of Deep Drilling Systems in Minneapolis, U.S.A., 2014, Organization of the 4th International Colloquium on Nonlinear Dynamics and Control of Deep Drilling Systems in Stavanger, Norway, 2018, and of the 7th Symposium of the European Network for Nonsmooth Dynamics, Eindhoven, The Netherlands.

- *Our international and national collaborative projects including academic institutions and industrial partners:* Horizon 2020: CONCORDA, 2018–2020, FP7 Network of Excellence HYCON 2 (2010–2013), FP7 Collaborative project iGAME (2013–2016), Horizon 2020 Marie Curie Training Networks TANGO (2012–2016), HYDRA (2016–2020) and UCoCoS (2016–2020), Horizon 2020 Research and Innovation projects Biohypp (2015–2019) and Everlasting (2016–2020), National Research (STW-Perspective)program: Integrated Cooperative and Automated

Vehicled (i-Cave) (6MEuro, 2016–2020), TTW project STABLE (2018-present), STW projects Thermo-acoustics (2009–2013), Acoustic shielding (2010–2014), HyperMotion (2011–2015) and CHAMeleon (2015–2019), NWO project HYMODRA (2016–2020), Point-one project 'Real-time vibration detection' (2011–2015) and Raakpro projects Aerobic (2012–2016), Intralog (2015–2018).

- *Our awards and grants:* Lopez Arteaga - Swedish Research Council (VR) Grant in 2012 and 2016, Fey & Nijmeijer (supervisors) - Tata Steel Prize for Mechanical Engineering and Material Science 2014 Besselink (supervisor) 2nd place E-car scriptieprijs 2011, Tom van der Sande, winner Spijkerprijs 2011 (500 euro),MSc thesis: Control of an automotive electromagnetic suspension. Van de Wouw, Nijmeijer, Heertjes - 2015 IEEE Control Systems Technology Award 'For the Development and Application of Variable-Gain Control techniques for High-Performance Motion Systems', Van de Wouw 2014 Best Teacher Award, M.Sc. Program of the Department of Mechanical Engineering, TU/e.

- *Our activities for research valorization and dissemination of knowledge to society:*

  - The research on Huygens' synchronization featured in most national newspapers and radio stations (NPO, BNR, Volkskrant, AD, ED, NRC, ...), 2016.
  - Nijmeijer, interviews/panelist on smart vehicles (ACEA, NOS news, Brabant news, Trazy Metz, etc) NWO-panel on Human Brain Project.
  - Nijmeijer/van de Wouw, (Co-)organization of and participation in the 2011 and 2016 Grand Cooperative Driving Challenge (GCDC2011, GCDC2016, see `http://www.gcdc.net/nl`) in The Netherlands.
  - Demos Cooperative Driving/Cooperative Adaptive Cruise Control: Ringroad Amsterdam, with Minister Schultz-Van Haegen as passenger, and with the presence of the Dutch press (NOS journaal, RTL journaal, Hart van Nederland, Jeugdjournaal), November 2013. Testdrives with King Willem Alexander on the A270 highway (Helmond-Eindhoven), June 2015.
  - Fey, *Antitriller*, publication in *De Ingenieur*, April 2015.
  - Ploeg, *Veel te dicht op elkaar, maar toch veilig*, in *De Volkskrant*, April 2014.

2.4 Prospects

The world is becoming increasingly interconnected, both between people and technological systems. Moreover, the opportunities and demand for further automation is recognized everywhere in society, e.g. in high-tech manufacturing, personalized care, automated driving, etc., due partly to the advancement of new sensor and actuator technology, novel communication technologies and lower-cost computational resources. Hence, we aim to contribute to the further development of automated and autonomous systems that can safely and effectively operate in a complex, interconnected and information-dense world. We will do

so by continuing to build the competences for integrating fundamental (mathematical) research on complex dynamical systems and data- and model-based modeling and control with advanced numerical/simulation tools and experimental/industrial benchmarking.

The Dynamics and Control section started in 2000, and in previous research assessments the group proven itself to have excellent viability. In the assessment period, we have shown this activity to be sustainable by gaining substantial funding from contract research sources, showing appreciation for the more fundamental and industrial/application side of our activities. Furthermore, Alessandro Saccon was appointed as assistant professor in the group, strengthening the robotics and nonlinear control activities. Group members are encouraged to write personal research plans (sponsored by EU and or national), as well as to obtain joint EU projects. The group fostered in the last decade two start-ups (Sorama and Rose bv) and stimulates further initiatives in this direction.

Furthermore, the strength of the Brainport region in high-tech systems and equipment is internationally recognized. This regional strength offers ample opportunities for joint projects in Dynamics and Control with leading industrial partners; the High-Tech Systems Center and the newly established Eindhoven Artificial Intelligence Systems Institute, EAISI (Nathan van de Wouw is steering board member of EAISI) are highly instrumental in fostering and expanding collaborative efforts with industry and society on developing the intelligent engineering systems of the future.

2.5 Publications, prizes and awards

Key publications in evaluation period

- Ploeg, J., van de Wouw, N., Nijmeijer, H., *Lp String Stability of Cascaded Systems: Application to Vehicle Platooning*, IEEE Transactions on Control Systems Technology, vol. 22(2), pp. 786-793, 2014.

- Matveev A., Pogromsky A., *Observation of nonlinear systems via finite capacity channels: Constructive data rate limits*, Automatica, vol. 70, August, 217-229, 2016.

- Murguia, C., Fey, R.H.B., Nijmeijer, H., *Network synchronization using invariant-manifold-based diffusive dynamic couplings with time delay,* Automatica, vol. 57, pp. 34-44, 2015 .

- E. Zea, L. Manzari„ G. Squicciarini, L. Feng, D. Thompson, I. Lopez Arteaga, *Wavenumber–domain separation of rail contribution to pass-by noise,* Journal of Sound and Vibration, 409, 24-42, 2017

- Saccon, A., Hauser, J., Aguiar, A.P., *Optimal control on Lie groups: The projection operator approach,* IEEE Transactions on Automatic Control, vol. 58 (9), 2230-2245, 2013

Scientific awards and scholarly prizes

- Nathan van de Wouw, Marcel Heertjes and Henk Nijmeijer received the 2015 IEEE Control Systems Technology Award 'For the Development and Application of Variable-Gain Control techniques for High-Performance Motion Systems' (2015)
- Johan van Hoof (MSc supervisors: Rob Fey and Henk Nijmeijer) was awarded with the Tata Steel Prize for Mechanical Engineering and Material Science 2014 (Euro 5000,-) for the best MSc graduation thesis in the Netherlands in this field by the Koninklijke Hollandsche Maatschappij der Wetenschappen (the Royal Holland Society of Sciences and Humanities) (2014)
- Henk Nijmeijer, Corresponding Member Mexcian Academy of Sciences (2016)

3 Energy Technology and Fluid Dynamics

Program leader	Prof.dr.ir. D.M.J. Smeulders	
Full professors	Prof.dr.ir. E.H. van Brummelen	1.0
	Prof.dr.ir. D.M.J. Smeulders	0.8
	Prof.dr.ir. A.H.M.E. Reinders	0.2
	Prof.dr.ir. J.M.R.J. Huyghe	0.2
	Prof.dr.ir. C.J. van Duijn	0.2
Associate professors	Dr.ir. M.F.M. Speetjens	1.0
	Dr.ir. H.C. de Lange	0.6
	Dr.ir. C.C.M. Rindt	0.4
Assistant professors	Dr.ir. A.J.H. Frijns	1.0
	Dr.ir. C.V. Verhoosel	1.0
	Dr.ir. S.V. Gaastra-Nedea	1.0
TU/e Fellows	Dr.ir. M.D. Boot	0.2
Extraordinary chairs	Prof.dr.ir. J.A.M. Dam	0.2
	Prof.dr.ir. H.M.A. Wijshoff	0.2
	Prof.dr.ir. H. Zondag	0.2

3.1 Mission and vision

Vision, mission and objective(s) of the program

The mission of ETFD is to advance heat & flow technologies for energy and high-tech applications. This mission encompasses the scientific development of new methods and tools (science); optimizing advanced systems (technology); transferring knowledge to application partners (valorization); and educating future generations of engineers (education).

Strategy

Scope: Energy Technology and Fluid Dynamics focuses on three fundamental research themes viz., Fluid-Solid Interactions, Renewable Energy Storage, and Cooling and Separation. In all three themes societal and scientific challenges are intertwined.

Means: We choose to operate in collaborative structures. We develop multi-disciplinary research activities funded by government, industry (Shell, GDF Suez, Wintershall, Total, Baker-Hughes, ASML, Océ), and EU. We collaborate intensively with other universities and institutes (TU Delft, Utrecht University, Maastricht University, TNO, ECN) and research groups within the TU/e and the Mechani-

cal Engineering department. Examples are the 2F2S consortium (www.2f2s.org), the compact heat storage consortium (www.projectcco.org), and the Darcy Center (www.darcycenter.org).

Resources: Research focus and mass are considered essential. The groups Energy Technology and Multiscale Engineering Fluid Dynamics successfully merged. We attract outstanding senior researchers for strengthening our group (prof. Huyghe, prof. Wijshoff, prof. Dam). We actively participate in the public debate.

3.2 Research themes

ETFD features three research themes, which are intimately linked to present-day societal and scientific challenges.

1. Fluid-solid interactions (FSI): this research theme is at the forefront of scientific developments and is synergetic to various application areas, e.g. hydraulic fracturing for geothermal applications, elasto-capillarity for inkjet printing processes and contamination control in photo-lithography machines. The scientific challenge is to couple fluid flow and structural behavior.
2. Renewable Energy Storage (RES) aims to develop new materials and systems for energy storage for domestic and industrial applications, in the form of heat and chemicals. The scientific challenge is to couple fluid flow and heat transfer in energy systems.
3. Cooling and Separation (CSEP): this research line focuses on industrial and domestic cooling systems. An example is the production of LNG by innovative gas pre-treatment steps where cooling and separation of contaminants are combined. A new research line on simulation methods for transport in rarefied gas flows was recently initiated. The scientific challenge is in the combination of (rarefied) gas flow and phase transitions.

3.3 Major accomplishments in the evaluation period

- Obtained spotlight position in the Energy transition
- Doubled the number of PhD students since 2011
- Number of journal publications increased by 58% since 2015
- Founding father of the Darcy Center within the TUE-UU-UMC strategic alliance
- Huyghe: Bernal Chair, University of Limerick, Ireland
- Smeulders: scientific director of TU/e Strategic Area Energy
- Smeulders: scientific director 4TU Resilience Center
- Smeulders: board member TKI Gas (since 2012) and TKI Urban Energy (from 2012 until 2016)
- Smeulders: board member of NERA (Netherlands Energy Research Alliance)

3.4 Prospects

The group is excellently positioned in the energy landscape, both at TU/e, through the Institute of Renewable Energy Storage (IRES), regionally through the Brainport region, and nationally through the Topsectors, the Darcy Center for porous media research and the NERA alliance. As the energy transition is in full sweep, we expect to continue to play an important role for TU/e here, with the emphasis on heat storage, which is unparalleled in the Netherlands by the cooperation with industry and TNO-ECN. With respect to high-tech applications, the group participates in the High Tech Systems Center with its flow-induced vibrations research, directly funded by ASML, TNO, and Philips Innovation Services, and in the FIP Industrial Partnership Program (Océ, TU/e, UTwente, NWO). The research on fracture initiation and growth is on the forefront of scientific research through the unique combination of expertise within ETFD (extended finite element methods and phase field techniques), where also the cooperation with the Mechanics of Materials Group is very productive.

	S	W
O	Emerging technologies: Fractures, Heat Storage, Flow-induced Vibrations, Inkjet printing	More focus and mass in emerging technologies. End others. Hire new staff to mitigate work load.
T	Consortium building against declining project funding. Use Grad School to attract talented PhD candidates.	Consortium building in emerging technologies limits both threats. (declining project funding) and weaknesses (too little focus).

3.5 Publications, prizes and awards

Key publications in evaluation period

- *Elucidation of the origin of chiral amplification in discrete molecular polyhedra*, Y. Wang et al., Dec 2018, Nature Communications 9, 1, 488
- *Printing wet-on-wet: attraction and repulsion of drops on a viscous film*, M.A. Hack et al., Oct 2018, Applied Physics Letters 113, 18, 5 p., 183701
- *Water nucleation in helium, methane, and argon: a molecular dynamics study*, L.R. Dumitrescu et al., 21 May 2018, In : Journal of Chemical Physics 148, 19, 194502
- *Energy density and storage capacity cost comparison of conceptual solid and liquid sorption seasonal heat storage systems for low-temperature space heating*, L. Scapino et al., Sep 2017, Renewable and Sustainable Energy Reviews 76, p. 1314-1331 18 p.
- *Frontiers of chaotic advection*, H. Aref et al., Jun 2017, Reviews of Modern Physics 89, 2, p. 1-66 66 p., 025007

TU/e's Darcy Lab. (Picture Bart van Overbeeke).

Scientific awards and scholarly prizes

- 'Nederlandse Gas Industrie' award Kingma, MSc (2016)
- Scholarship in the NWO excellence program 'Fluid and Solid Mechanics', De Prenter MSc (2016)
- Cum laude PhD (top 5%), Remij (2017)

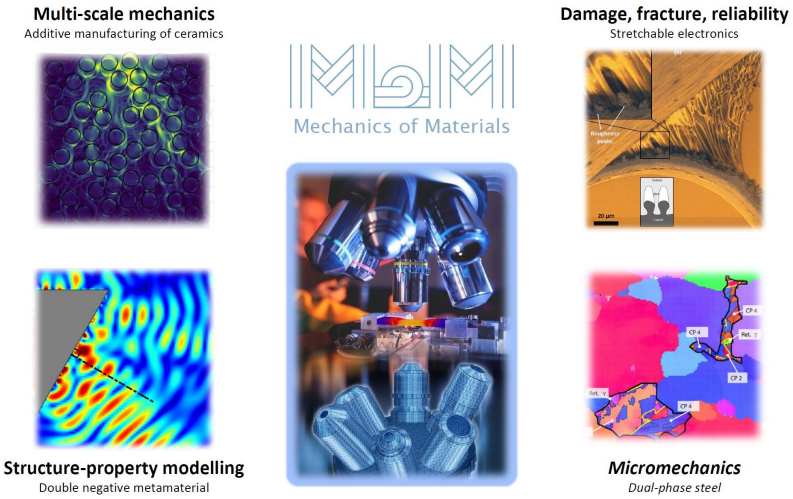
4 Mechanics of Materials

Program leader	Prof.dr.ir. M.G.D. Geers	
Full professors	Prof.dr.ir. M.G.D. Geers	1.0
	Prof.dr.ir. V.S. Deshpande (until Jan 1st 2018)	0.2
Associate professors	Dr.ir. J.A.W. van Dommelen	1.0
	Dr.ir. J.P.M. Hoefnagels	1.0
	Dr.ir. V.G. Kouznetsova	0.9
	Dr.ir. R.H.J. Peerlings	1.0
	Dr.ir. J.J.C. Remmers	1.0
	Dr.ir. O. van der Sluis	0.2
Extraordinary chairs	Prof.dr. N.A. Fleck – Distinguished TU/e prof.	0.0

4.1 Mission and vision

The mission of the *Mechanics of Materials* section is to understand, predict and optimize the mechanical response of high-tech materials and products as a function of their underlying microstructure, processing and usage, through focused and coordinated experimental, theoretical and computational efforts. High-tech materials are key in developing novel products with revolutionary functionality. Our vision is that by carrying out dedicated world-class research across a range of length scales, we will be able to contribute to the growing demands in society and industry. Our research program therefore establishes a strong link between application, experiment, theory and computation. The objective of the Mechanics of Materials program is to play a leading international role in our discipline, aiming for the highest scientific level, and thereby addressing the most challenging industrial questions to the benefit of society and the young engineers and scientists that we educate.

The Mechanics of Materials section pursues a generic research strategy that is systematically aligned with long-term industrial needs, from which fundamental and scientifically challenging research questions are distilled. To reach a high scientific level, we focus on specific key problems in mechanics of materials, aligned with our research subprograms. The strategy for generating a healthy project portfolio is therefore based on different funding sources, containing both research grants (NWO, ERC/EU) and contract research (Industry, M2i). Another important element of our strategy is the training we provide to our students at BSc, MSc and PhD levels. Our PhD educational program is embedded in the Engineering Mechanics (EM) graduate school, through which we provide training and courses covering professional skills (via TU/e) and high-level technical subjects (via EM).



4.2 Research themes

The main challenge addressed in the research program is the accurate prediction of the mechanical properties of materials, structures and components with complex microstructures. This entails research on intrinsic material properties (dynamic metamaterials, multi-scale plasticity in advanced steels, interfacial properties in laminates, additively processed materials, etc.), on the application of materials in high-tech systems (i.e. multi-phase functional materials, MEMS, stretchable electronics, paper for printing, etc.) and on various systems and processes involving mechanically complex interfaces (e.g. in Systems-in-Package, flexible displays, electronic textiles). A systematic and integrated numerical-experimental approach is generally adopted for this purpose. The research activities are organized in three subprograms:

1. *Multi-scale mechanics and structure-property modeling.* Upscaling from microstructure towards engineering properties requires advanced methods to extract relevant information from small scales and reveal the emergent behavior at larger scales.

2. *Computational and experimental micromechanics.* This subprogram focuses on the development of advanced physical models, computational tools and state-of-the-art experimental techniques to study the mechanics of microstructures at the micro-scale.

3. *Damage, fracture and reliability.* This subprogram develops the in-depth understanding of damage and failure phenomena and provides powerful models and computational solution strategies, along with dedicated integrated numerical-experimental identification methods.

The *Multi-Scale lab* of the Mechanics of Materials section takes a rather unique position as it bridges the gap between traditional materials science and mechanical characterization, by integrating mechanical testing with (real-time and in situ) microscopic observation. The lab perfectly fits in the research section's mission, and enables a symbiosis between computational modeling and advanced experimentation across the scales.

4.3 Major accomplishments in the evaluation period

Research quality and scientific relevance

Citation analyses typically show a strong citation impact for the Mechanics of Materials section. In the previous research assessment (2014), the section received the maximum score on all evaluation items. Our most significant results in the period 2013–2018 are summarized below, spanning the section's three research themes.

1. *Multi-scale mechanics and structure-property modeling.* In the past period, we have pushed the frontiers in multi-scale mechanics on the basis of novel methods to new applications. The main results in this regard are: (a multi-scale methods dealing with localization of deformation; (b) multi-scale methods for fibrous networks; (c) multiscale methods for acoustic foams and metamaterials; (d) multiscale model for traumatic brain injury. The section's papers on multiscale mechanics of the past 10 years have been cited 2550 times (Web of Science, period 2008–2018, August 2019).

2. *Computational and experimental micromechanics.* This research theme focused on: (a) state-of-the-art micro-mechanics based models for plasticity in metals (based on physically based models for dislocation interactions); (b) time-dependent deformation of metallic RF-MEMS at small length scales; (c) delaminating cohesive interfaces in metal-polymer based systems; (d) constraining interfaces, in particular metallic grain and phase boundaries. The section's papers on these subjects of the past 10 years have been cited 2039 times (Web of Science, period 2008–2018, August 2019).

3. *Damage, fracture and reliability.* The section has a long tradition and acknowledged expertise in the field of damage mechanics. The main achievements here are: (a) large deformation ductile damage models coupled to propagating cracks in 3D ductile solids; (b) the development of partition of unity based models for multiple, interacting cracks and dynamic crack growth; (c) experimental ductile damage quantification; (d) low-cycle thermomechanical fatigue for cast iron cylinder heads; (e) advanced experimental and computational methods for the characterization of damage in multi-phase metallic materials. The section's papers on advances in damage, fracture and reliability of the past 10 years have been cited 2390 times (Web of Science, period 2008–2018, August 2019).

Valorization & Societal impact

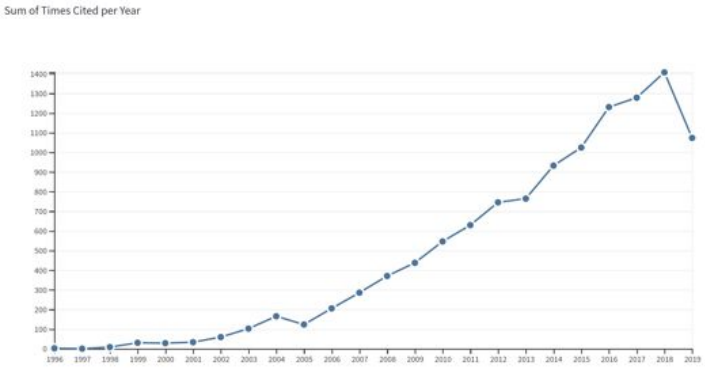
The societal relevance of the work in the Mechanics of Materials section is strongly linked to its close interactions with industry. Almost all research projects originate from an industrial problem and have at least one industrial partner involved in the execution of the project. The resulting research topics are therefore driven by a range of societal needs, e.g., high-tech systems, mobility, energy, the environment, healthcare.

International positioning & roles of the MoM section members 2013–2018:

- 2 Assoc. Editor roles: Geers (Eur. Jnl. Mechanics A/Solids); Hoefnagels (Strain)
- 19 Editorial Board roles, involving all faculty members
- 3 Guest editor roles
- > 70 PhD committee memberships, in The Netherlands, Belgium, France, Germany, Spain, Denmark, Sweden, United Kingdom, Ireland, Norway, Luxemburg
- > 25 roles in the Organization of international conferences and symposia
- > 75 membership roles in Scientific Conference Committees
- Member of the EUROMECH Council
- Chairman of the European Mechanics of Materials EMMCC committee
- Member of the General Assembly of the International Union of Theoretical and Applied Mechanics
- Member of the Editorial Committee of the Éditions de l'École polytechnique
- Member of the GAMM research group on Multiscale Material Modeling
- Member of the GAMM research group on Analysis of Microstructures
- Dutch representative of the European Structural Integrity Society (ESIS)
- Member of the council of the European Association for Experimental Mechanics (EURASEM)

Scientific recognition and impact in the period 2013–2018:

- Prestigious Grants & Awards: ERC Advanced Grant 2013 (Geers), VIDI Grant 2013 (Hoefnagels), Fellow Award of the European Mechanics Society (Geers), IACM Fellow Award 2016 (Geers);
- 11 Plenary Lectures (e.g. ESMC, PCM-CMM, IWCMM, ICOMP, EMMC, WCCM, BSSM-ICAEM)
- 15 Keynote Lectures
- > 115 Invited Lectures & Seminars
- h-index of the section's research output
  - Web of Science = 53 with 451 papers and 11475 citations
  - Scopus = 63 with 586 papers and 15134 citations



- Other research awards:
  - Biezeno Award, best PhD thesis in Solid Mechanics in the Netherlands, Francesco Maresca, 2015.
  - Stahl Young Academics Steel Award for the best PhD thesis in metallurgy in Europe, 2016 (Maresca).
  - Martinus van Marum award for the best PhD thesis (KHMW), 2017 (de Geus)
  - 6 EM Poster Awards and 6 EM Presentation awards at the Engineering Mechanics symposia
  - Cum Laude PhD for Francesco Maresca (2015) and Tom de Geus (2016).

4.4 Prospects

The research in Mechanics of Materials sets out novel directions in the research field. Among these, the following research topics hold great potential, and are presently addressed in newly started projects or research proposals:

- Structure-property relations in additive manufacturing of metals, ceramics and multi-materials
- Mechanics of materials in extreme conditions (e.g. the plasma-wall interaction in fusion)
- Advanced multi-scale methods for identifying emergent behavior
- Analysis and design of novel metamaterials (e.g. for acoustic shielding)
- Mechanics of the next generation electronics (rollable, stretchable, printable)
- Mechanics of miniaturization (applications in systems-in-package and lab-on-a-chip devices etc.)
- Damage-resistant materials and damage engineering
- Advanced composites for light-weight applications
- Full symbiosis between experiments and simulations by advancing the Integrated Digital Image Correlation method (IDIC)

The strategy of the Mechanics of Materials section is driven by: new challenges; scientific quality; the strengths of our discipline-oriented research expertise; industrial and societal impact; international reputation; focus on excellent MSc and PhD students; balanced financial resources. Impact metrics determined for the past and previous research periods indicate that the section is successful in making impact in the field. The research topics for the future are also selected according to their impact potential, both scientifically as well as societally. The research section has secured ample research funding for the present and coming years. At present, we are working on the science of additive manufacturing, novel models for complex interfaces, novel methods to unravel and design mechanical metamaterials, novel methods to bridge scales combined with reduced-order approaches, and multi-physics problems.

4.5 Publications, prizes and awards

Key publications in evaluation period

- F. Maresca, V.G. Kouznetsova, M.G.D. Geers. *On the role of interlath retained austenite in the deformation of lath martensite.* Modeling and Simulation in Materials Science and Engineering 22(4), article 045011, 2014.
- J. Neggers, J.P.M. Hoefnagels, M.G.D. Geers, F. Hild, S. Roux. *Time-resolved integrated digital image correlation.* International Journal for Numerical Methods in Engineering 103(3), 157-182, 2015.
- A. Sridhar, V.G. Kouznetsova, M.G.D. Geers. *Homogenization of locally resonant acoustic metamaterials towards an emergent enriched continuum.* Computational Mechanics 57(3), 423-435, 2016.
- T.W.J. de Geus, J. Vondrejc, J. Zeman, R.H.J. Peerlings, M.G.D. Geers. *Finite strain FFT-based non-linear solvers made simple.* Computer Methods in Applied Mechanics and Engineering 318, 412-430, 2017.
- S. Westbeek, J.A.W. van Dommelen, J.J.C. Remmers, M.G.D. Geers, *Multiphysical modeling of the photopolymerization process for additive manufacturing of ceramics.* European Journal of Mechanics A/Solids 71, 210-223, 2018.

Scientific awards and scholarly prizes

- ERC Advanced Grant, Marc Geers (2013)
- VIDI grant, Johan Hoefnagels (2013)
- IACM Fellow Award for Marc Geers (2016)
- KIVI Biezeno Solid Mechanics Award & Young Academics Steel Award, Francesco Maresca (2016)
- Martinus van Marum Award, Tom de Geus (2017)

5 Microsystems

Program leader	Prof.dr.ir. J.M.J. (Jaap) den Toonder	1.0
Full professors	Prof.dr.ir. J.M.J. (Jaap) den Toonder	1.0
Associate professors	Dr. R. (Regina) Luttge	1.0
Assistant professors	Dr. H.M. (Hans) Wyss	1.0
	Dr.ir. Y.B. (Yoeri) van de Burgt	1.0
	Ir. F.G.A. (Erik) Homburg	0.4

5.1 Mission and vision

Trends in microsystems science and technology are the ongoing miniaturization, increased functional integration, adaptivity to environment conditions, interaction and merging with biological materials, and low-cost manufacturing approaches. The mission of the Microsystems research section is to carry out excellent scientific and technologically driven research that contributes to these developments, by developing innovative design concepts and demonstrator microdevices in combination with novel fabrication methods, often inspired by biology, for a wide range of applications. We want to enable life-enhancing applications through research at the micro-scale.

What distinguishes the group from other (national, international) research groups is the unique combination of a wide variety of micro-fabrication approaches with active microfluidic technology, integration with biology, and bio-inspired engineering. Concrete applications of the group's research range from organ-on-a-chip systems for cancer and brain research, point-of-care diagnostics, wearable health sensors, water and air quality monitoring and purification, lithography machines, displays, and brain-inspired computing, to soft micro-robotics. The demands for these application areas will continue to grow rapidly in the coming years. To develop these applications, we collaborate with biomedical, clinical, and industrial partners. An important element of the group's strategy has been the realization of a state-of-the-art micro-fabrication laboratory, the Microfab/lab, opened in 2015, that currently acts as the interdepartmental micro-manufacturing center of the TU/e.

5.2 Research themes

The Microsystems section, headed by Jaap den Toonder, is structured around the senior scientists Regina Luttge, Hans Wyss, Yoeri van de Burgt, Erik Homburg and the section head, who collectively hold expertise in micro-and nanotechnology, laser microfabrication, microfluidics, microsystems design, and in-vitro testing of

cells and tissues and system's modeling. Industrial research fellow Eduard Pelssers (Philips) and our technical (Irene Dobbelaer, Jaap de Hullu) and administrative co-workers (Liesbeth van Ballegooij) complete the staff of the section.

The section's research is carried out in 4 subprograms or groups, each driven by one of the PI's of the section. There is much collaboration between the subprograms, and all of the research is carried out in the Microfab/lab that forms a natural environment for sharing knowledge and know-how, as well as stimulating novel ideas. Hence, the Microfab/lab is central to all of the research projects.

1. *Microfluidics and micro-actuation (den Toonder).* In microfluidic systems, active control of fluids and species is essential. Examples are fluid pumping, mixing, mechanical actuation, sorting of cells and particles, and biomolecule capture for diagnostics. We develop and apply micro-actuators, responsive surfaces, and magnetic bead actuation systems, to realize these functions. Our approaches are often biologically inspired. As an important application of our microfluidic systems, and in collaboration with biological, biomedical, and clinical groups, we develop biomedical microdevices to study and understand the behavior of cells, tissues, and organs, with the aim to eventually enable novel therapies and medicines. Specifically, we develop organs-on-chips as in-vitro disease models focusing on cancer, microdevices for in-vitro diagnostics, and devices that can be applied to treat patients non-invasively, such as a glaucoma eye implant. We also develop new concepts for micro-actuators for other applications, from lithography machines to new display principles to soft microrobotics.

2. *Neuro-nanoscale engineering (Regina Luttge).* In this cross-disciplinary research theme, we investigate microsystems for medicine and biology with integrated bio-inspired functionality. We apply emerging and established micro-nano-fabrication methods. The specific goal is to combine microfluidics with tissue

engineering to create a realistic miniaturized in vitro model of the nervous system and the brain in particular. These systems can provide insights into both normal and disease-state function. To forward-engineer a living nervous systems tissue-on-chip from neuronal stem cells, we design, realize, test artificial micro-environments with a focus on cell-type specific differentiation and physiological relevance of hierarchical architecture within these tissues.

3. *Microfluidics and Soft Matter (Hans Wyss).* We develop and use simple experimental tools, often based on microfluidics technology, for studying the mechanics, dynamics and structure of complex soft materials. Examples of materials studied include colloidal suspensions and gels, emulsions, foams, biological systems, and polymers. The broad range material behavior that soft materials can exhibit is one of the reasons why they are encountered in many applications; at the same time, they hold a tremendous potential for studying fundamental scientific questions that are relevant to the behavior of all materials. A key expertise of the group is the measurement of mechanical properties of soft materials at small length scales. Further focal points are the study of the mechanics and dynamics of microgel particles, and the study of phoretic forces acting on colloidal particles, whereby the group has recently shown that these are responsible for the previously unexplained "exclusion-zone" effect, an intriguing long-range repulsion of colloidal particles from a solid surface.

4. *Neuromorphic engineering (Yoeri van de Burgt).* Just started in 2017, this multidisciplinary research group spans materials science, bioelectronics, electrical engineering and device physics. The group focuses on organic electronic and neuromorphic materials, with specific applications in adaptable bioelectronics and brain-inspired smart point-of-care diagnostic devices.

5.3 Major accomplishments in the evaluation period

Microsystems is a relatively young research section: it was founded in May 2013, when Jaap den Toonder was appointed as full-time professor heading the section. Associate professor Yves Bellouard and assistant professor Erik Homburg, both from the former Micro- and Nano-Scale Engineering group at the department, joined the group from the start. Regina Luttge was appointed as associate professor in June 2013 to strengthen the team. Since then, the team still has gone through a number of changes in composition: Yves Bellouard left the group in Jan. 2015 to take up a professorship at EPFL, Hans Wyss joined the group as an assistant professor at the same time, and Yoeri van de Burg was appointed as assistant professor in November 2016, anticipating the partial retirement of Erik Homburg in the fall of 2017. Despite these changes, the research section has successfully kept a steady direction following the mission defined from the start.

An essential milestone for the section was the realization of the Microfab/lab, operational from April 2015, and officially opened in July 2015. On the initiative of

Jaap den Toonder, this lab was designed as a uniquely versatile micro-fabrication facility, combining a range of methods such as photolithography, laser fabrication, precision micro-machining, 3D-printing, thin film deposition, and surface treatments, as well as housing a bio-lab and a microfluidic testing lab. The Microfab/lab constitutes the instrumental basis for the section's research and teaching. The Microsystems section is managing the Microfab/lab, however it is accessible for other groups in the department, other TU/e departments, and external collaborators. This means that the Microfab/lab is a vibrant meeting place where many different disciplines meet.

The section publishes its research in the highest ranked scientific journals in our field and its papers are highly cited, clear evidence of the international recognition of the section. We have published our work for example in i. Also, the scientific staff members of the section are frequently invited to give lectures and seminars at international conferences and at other institutes and companies.

Our mission and steady research direction have also resulted in major funding of the section's research. Yoeri van de Burgt received an ERC Starting Grant (2017), Regina Luttge obtained an ERC Proof-of-Concept Grant (2016) as well an EU FET-PROACT Grant (2018), and Jaap den Toonder was awarded an ERC Advanced Grant (2018).

5.4 Prospects

The first 4 years of existence of the Microsystems section can be characterized as the "build-up phase" in which the section's direction was defined, the section composition was formed, the infrastructure was realized (i.e. the Microfab/lab), and collaborations were established. A solid foundation was laid on which the section could build further and establish a stable scientific research program, which point is now almost reached. Next to major funding, these efforts have resulted in a large network with industry and with other university groups.

The section operates at the frontiers of the scientific and technological field of microsystems. The focus on novel out-of-cleanroom micro-fabrication methods, integration with biology, and bio-inspired engineering, leads to exciting scientific challenges lying ahead for the coming decades. At the same time, the research topics of the section match with future needs of society and industry equally. The biomedical applications we work on can contribute to solve grand challenges in healthcare, specifically, for personalized diagnostics and development of novel disease therapies (especially in cancer and neurodegenerative diseases). In the area of fabrication, the aspects of miniaturization, novel micro-fabrication methods, and biologically inspired engineering are relevant to the high-tech industry in the region as well as worldwide. Currently, we have strong collaborations with Philips, ASML, as well as biotech companies and clinical groups in a number of

running projects. This underlines our added value and impact on research valorization. In combination with the secured funding for fundamental scientific research, we are confident that the future of the Microsystems research section is bright.

5.5 Publications, prizes and awards

Key publications in evaluation period

- Zhang, S., Wang, Y., Onck, P.R., Toonder, J.M.J. den (2018). *Removal of Microparticles by Ciliated Surfaces—an Experimental Study.* Adv. Funct. Mater., 1806434.
- Eslami Amirabadi, H., Sahebali, S., Frimat, J.P., Luttge, R., Toonder, J.M.J. den (2017). *A novel method to understand tumor cell invasion: integrating extracellular matrix mimicking layers in microfluidic chips by 'Selective Curing'*. Biomedical Microdevices 19: 92.
- Frimat, J.-P., Xie, S., Bastiaens, A., (…), Den Toonder, J., Luttge, R. (2015). *Advances in 3D neuronal cell culture.* Journal of Vacuum Science and Technology B: Nanotechnology and Microelectronics 33(6),06F902
- Florea, D., Musa, S., Huyghe, J.M., Wyss, H.M. (2014). *Long-range repulsion of colloids driven by ion-exchange and diffusiophoresis.* Proceedings of the National Academy of Sciences of the United States of America (PNAS), 111(18), 6554-6559.
- van de Burgt, Y., Lubberman, E., Fuller, E. J., Keene, S. T., Faria, G. C., Agarwal, S., … Salleo, A. (2017). *A non-volatile organic electrochemical device as a low-voltage artificial synapse for neuromorphic computing.* Nature Materials, 16, 414-418.

Scientific awards and scholarly prizes

- EuronanoForum 2013 Best Project Finalist Award, Yves Bellouard (2013)
- ERC Proof-of-Concept Grant, Regina Luttge (2016)
- ERC Starting Grant, Yoeri van de Burgt (2017)
- ERC Advanced Grant, Jaap den Toonder (2019)

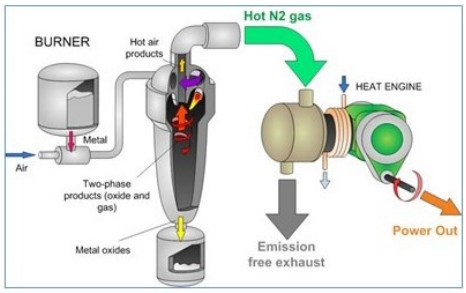
6 Power & Flow

Program leader	Prof.dr.ir. N.G. Deen	since 01-01-2016	
Full professors	Prof.dr.ir. J.J.H. Brouwers	until 09-2014	1.0
	Prof.dr.ir. N.G. Deen	since 01-2016	1.0
	Prof.dr. L.P.H. de Goey	0.5 fte dean since 2011	0.5
	Prof.dr. J.G.M. Kuerten	0.6 fte since 05-2019	1.0
Associate profs.	Dr.ir. R.J.M. Bastiaans	away 10-2015 till 08-2016	1.0
	Dr. N.J. Dam		1.0
	Dr. B.P.M. van Esch		1.0
	Prof.dr. C.W.M. van der Geld	until 12-2015	1.0
	Dr.ir. L.M.T. Somers		1.0
	Dr.ir. J.A. van Oijen		1.0
Assistant profs.	Dr.ir. M.D. Boot	until 12-2018	0.5
	Dr. B.P.M. van Esch	until 07-2019	1.0
	Dr. G. Finotello	since 10-2019	1.0
	Dr.ir. T.A.M. Homan	since 03-2018	1.0
	Dr.ir. H.P. van Kemenade	until 12-2016	1.0
	Dr.ir. N.C.J. Maes	since 06-2019	1.0
	Dr. Y. Tang	since 04-2017	1.0
Part-time	Prof.dr. M. Golombok		0.2
	Prof.dr. B. Johansson	until 12-2015	0.2
	Prof.dr.ir. D.J.E.M. Roekaerts	since 05-2016	0.2
	Dr.ir. X.L.S. Seykens	since 06-2016	0.2
	Prof.dr.ir. A.W. Vreman	since 04-2017	0.2

6.1 Mission and vision

In view of the continuous increase in world energy demand, our vision is that combustion will remain a very important energy conversion process, even in the far future when fossil fuels are depleted, since heavy transport by road, air and water along with industrial heat generation will require dense energy carriers, in other words liquid or solid fuels. An important issue in the future of combustion is the shift to ultra-clean and highly efficient combustion methods. The second important issue is related to the fuel aspects: we will see increased use of biofuels, and in the longer term the emergence of energy carriers derived from sustainable sources like solar fuels and metal fuels. Either way, it remains of utmost importance to optimize combustion devices, in combination with different fuel formulations to

Efficient Engines



Metal Fuels

minimize undesired emissions and maximize thermal efficiency. With the current level of development of practical combustion systems, further improvements will depend on details of the combustion-system and fuel-composition combination. More accurate and efficient validated models are required to describe the complex interplay between multiphase and/or reactive flows. All these topics fall within the broader theme of process technology, which combines complex flow phenomena with physical and chemical conversions.

The mission of the section is to provide education and to perform world-class scientific research on multiphase and reactive flows in the area of energy conversion and process technology, building a knowledge chain consisting of: 1) fundamental models based on first principles 2) experimental validation of these models using sophisticated (laser diagnostic) measurement systems 3) application and lab-scale demonstration of (reactive) multiphase contact equipment 4) predictive tools for practical and industrial applications, derived from the fundamental models based on first principles and experiment.

6.2 Research themes

The research of the section is concentrated around three main research topics: 1) Combustion systems and sustainable/renewable fuels. This concerns the development of combustion strategies for future ultra-clean and efficient combustion systems as well as of the after treatment, with a focus on future heavy-duty engine technology. With respect to fuels we focus on two main activities: i) using microstructuring gas-liquid bubbly flow processes to intensify biogas-to-liquid conversion ii) use of renewable (bio-based) fuels including alcohols, ethers, hydrogen and ammonia. 2) Metal fuels as dense CO_2-free energy carriers. Metal powders have a tremendously high energy density and can act as a major CO_2-free energy carrier for the long term. Within the section we develop the combustion technology of metal powder, solid handling including separation and regeneration through chemical reduction. 3) Complex multiphase flows. Various applications in the field of process technology involve complex multiphase flow phenomena. This includes equipment with phase transitions, such as evaporation of sessile

Research topic		TRL1	...	TRL4	TRL 5
Engines and fuels	Exp.	Dam	Maes Somers	Somers	
	Num.	Van Oijen De Goey	Somers Bastiaans	Somers	Seykens
Metal fuels	Exp.	Dam	Finotello		Golombok
	Num.	Van Oijen De Goey Bastiaans	Tang Deen	Roekaerts	
Multiphase flows	Exp.	Homan Deen	Van Esch	Golombok	
	Num.	Kuerten Tang Deen	Bastiaans	Van Esch	Vreman

multi-component ink droplets, cooling of steel by water jets and green hydrogen production through electrolysis.

The current/near future involvement of the different staff members is indicated in the table below.

6.3 Major accomplishments in the evaluation period

- Heat flux method P&F is the inventor of one of the most accurate ways to measure the adiabatic burning velocities of flames, used by more than 30 groups worldwide.
- Flamelet generated manifolds P&F is the inventor of this technique to accurately, yet efficiently calculate and tabulate complex combustion chemistry in combustion flow simulations. It is the industrial standard in current combustion CFD tools, also used by more than 30 groups worldwide.
- Future engines and their fuels P&F is key player of the strong Engine Combustion Network (ECN, ecn.sandia.gov). Our facilities compare very well with the best in the world. To be optimally prepared for the future the engine test cells in the Zero-Emission Lab (ZEL) will be completely renovated in 2020.
- Metal fuels P&F is one of the first groups worldwide to study the complete metal fuel cycle, in which metal particles act as a new class of promising CO_2 free dense energy carriers.
- Intensified gas-liquid processes As evidenced by a number of plenary lectures at international conferences, P&F is a world player in the field of reactive gas-liquid bubbly flow modeling and simulation. Two important applications are

studied in this respect: 1) green conversions (i.e. hydrogenation of CO_2 and H_2 production), and 2) intensification of gas-liquid contactors.

- Phase-transitional flows P&F is at the fore front of developing DNS models for phase-transitional flow.

International positioning and roles of the P&F section

- Editor-in-chief role: De Goey (Proceedings of the Combustion Institute ProCI, 2010–2013, together with Prof. Sick)
- Executive Editor role: Deen (Chem.Eng.Sci., since 2017)
- 2 Associate Editor roles: van Esch (ASME Journal of Fluids Engineering, 2012–2018); Deen (Chem.Eng.Sci., 2014–2016)
- 4 Editorial Board roles: De Goey (Adv. Appl. Phys., since 2010), (J. Thermodyn., since 2008), (Open Thermodyn. J., since 2007), Kuerten (Int. J. Multiphase Flow), Van Esch (Exp. Therm. Fluid Sci.)
- 4 Guest editor roles: Chem.Eng.Sci. (Deen), Flow Turbulence and Combustion (Kuerten 3x)
- 4 International courses at the PhD level: van Oijen (1), Somers (1), de Goey (2)
- 21 Roles in the organization of international conferences and symposia (De Goey, 10; Roekaerts, 1; van Esch, 3; van Oijen, 3; Kuerten, 4)
- 14 membership roles in Scientific Conference Committees (Roekaerts, 3; van Oijen, 3; Kuerten, 3; van Esch, 4; Bastiaans, 1)
- 3 Visiting Professor (De Goey, Beijing Institute of Technology, China, 2010-present; Bastiaans, Center for Turbulence Research, Stanford, University/Nasa Ames, 2012; van Esch, Jiangsu University, China, 2017-present)
- Role in about 20 different international research assessments and evaluation panels.

Scientific recognition and impact in the period 2013–2018

- 11 Plenary Lectures, e.g. De Goey 7; Kuerten 1; Deen 3
- 10 Keynotes, e.g. Roekaerts 1; van Esch 1; Bastiaans 1; van Oijen 6; Deen 1

6.4 Prospects

In Jan. 2016 the Combustion Technology and Process Technology groups merged to form the Power & Flow section. By combining the expertise on combustion and multiphase flow, a strong combination is created. The section is very well positioned for the future in terms of staff, labs and finances. P&F has a strong funding rate of around 1.5-2 M€ per year. The last years we experienced a temporary reduction in the funding rate, which was related to the restructuring of the section.

Moreover, the new research theme of metal fuels is still in an early phase. We expect to raise 0.5-1 M€ per year on this topic in the next years. In the past years, the section's industrial network was tightened by appointing/extending part time positions (Prof. Golombok, Shell; Prof. Roekaerts, TU Delft; Dr. Seykens, TNO and Prof. Vreman, AkzoNobel/Nouryon). Moreover, four talented assistant professors (3 female, 1 male) were attracted. Laboratories The labs and technical support staff are of top quality and have all the currently necessary equipment. To keep the research equipment up to date, the section invests around 400 k€/year, which is possible thanks to the section's strong funding. To keep the labs fit for the future, they will be completely renovated in the coming years (Zero-Emission Lab, ZEL in 2020, other labs in 2022). The perspective of the ZEL will be secured through a long-term collaboration between our section, TNO, DAF, Shell and the province of Noord Brabant. In this public-private partnership we will develop ultraclean yet efficient engines running on renewable fuels. We aim to bridge the gap between the low TRL levels in the section via intermediate TRL levels at TNO towards high TRL levels at the involved companies. We will develop and demonstrate metal fuels on the scale of a 100 kW steam system in close collaboration with the Metalot Campus in Cranendonck (see http://www.metalot.nl/). De Goey is founder and chair of the Metalot innovation center: Metalot Circularity Center Cranendonck.

6.5 Publications, prizes and awards

Key publications in evaluation period

- *Predicting diesel combustion characteristics with Large-Eddy Simulations including tabulated chemical kinetics*, Bekdemir, C., Somers, L. M. T., Goey, de, L. P. H., Tillou, J. & Angelberger, C., 2013, In : Proceedings of the Combustion Institute. 34, 2, p. 3067-3074 8 p., cited 70 times

- Goswami, M., Derks, S.C.R., Coumans, K., Slikker, W.J., de Andrade Oliveira, M.H., Bastiaans, R.J.M., Luijten, C.C.M., de Goey, L.P.H., Konnov, A.A. (2013). *The effect of elevated pressures on the laminar burning velocity of methane+air mixtures*, Combustion and Flame, 160 (9), pp. 1627-1635, cited 64 times.

- Vreman, A.W., Kuerten, J.G.M. (2014). *Comparison of direct numerical simulation databases of turbulent channel flow at Reτ = 180*, Physics of Fluids, 26 (1), 015102, cited 92 times.

- Sutkar, V.S., Deen, N.G., Patil, A.V., Salikov, V., Antonyuk, S., Heinrich, S., and Kuipers, J.A.M. (2016). *CFD-DEM model for coupled heat and mass transfer in a spout fluidized bed with liquid injection*, Chemical Engineering Journal, 288, pp. 185-197, cited 46 times.

- Van Oijen, J.A., Donini, A., Bastiaans, R.J.M., ten Thije Boonkkamp, J.H.M., and De Goey, L.P.H. (2016). *State-of-the-art in premixed combustion modeling using*

flamelet generated manifolds, Progress in Energy and Combustion Science 57, pp. 30-74, cited 74 times

Scientific awards and scholarly prizes

- KIVI/Niria prize for best master thesis: Wustmans (2013) Cum laude PhD defenses (top 5%): Coen Baltis (2014), Noud Maes (2019)
- NVV Combustion Award best MSc Thesis: Wustmans (2013), Willems (2016)
- Society of Automotive Engineers' John Johnson Award for Outstanding Research in Diesel Engines: Noud Maes, Bart Somers (2017)
- JMBC Young Scientist Award for the best oral presentation at the Burgers symposium: Noud Maes (2017)
- SAE Award for Excellence in Oral Presentation Noud Maes (2017 & 2018)
- Simon Stevin Meester Award (500,000 euro, sometimes called the Dutch Nobel prize on technology, 2010–2015): De Goey (2010)
- Fellow of the Combustion Institute: De Goey (2018)

7 Polymer Technology

Program leader	Prof.dr.ir. Patrick D. Anderson	1.0
Full professors	Prof.dr.ir. Patrick D. Anderson	1.0
	Prof.dr.ir. Gerrit W.M. Peters	1.0
Associate professors	Prof.dr.ir. Leon E. Govaert	0.8
	Dr.ir. Martien A. Hulsen	1.0
	Dr.sc.nat Markus Hütter	1.0
	Dr.ir. Albert Poortinga	0.2
Assistant professors	Dr.ir. Lambèrt C.A. van Breemen	1.0
	Dr.ir. Ruth M. Cardinaels	1.0
	Dr.ir. Tom A.P. Engels	0.2

7.1 Mission and vision

The mission of the program is to provide education and conduct research in the broad area of Polymer Technology, i.e. in the (industrial) arts of manufacturing polymer-based products. Design of polymer products and shaping processes benefit from a change from experimentally driven trial-and-error to virtual prototyping with quantitative predictive capability. The main objective is to provide the fundamental knowledge and models required for the prediction and understanding of structural evolution during processing of polymers and provide reliable estimates of the resulting mechanical properties in the final products already in the early stages of design. These properties are determined by intrinsic (molecular) material parameters and, to a great extent, by the processing conditions.

To reach this goal, the program aims at bridging the gap between sophisticated rheological models and reliable and feasible predictive modeling of polymer mechanics and processing. The research is aided by sophisticated commercial and in-house developed experimental setups for flow, rheology and mechanics. This scientific approach is not limited to classical polymer processes, but also applied to soft matter, food, and modern processes like Additive Manufacturing (AM). During the Review Period 7 PhD AM projects started studying fundamentals of Industrial AM processes (Selective Laser Sintering (SLS) and Stereo Lithography (SLA)) using powder and UV-curable polymers respectively.

The Polymer Technology group has strong long-lasting collaborations with industry. This is directly visible from the two part-time faculty members (Engels from DSM and Poortinga from FrieslandCampina /Bether Encapsulates) but also reflected by the large number of PhD and postdoctoral projects bilaterally funded by Dutch, European and overseas industrial partners. In particular, our local indus-

trial partners also have great interest in our education program and the teaching of our students in the area of rheology, processing and properties of polymers. After graduating these students easily find jobs, some in academia but most of them in industry and it is this cycle of funding, research, valorization and education that is the foundation of our societal existence.

7.2 Research themes

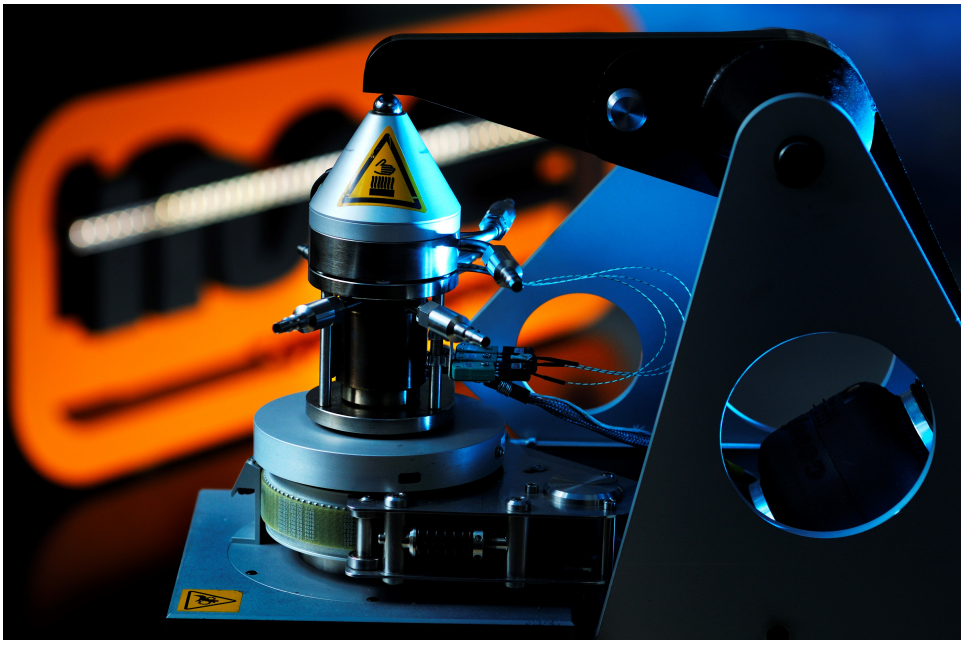
Research within Polymer Technology starts with the polymer molecular architecture and constitutive equations at the continuum level, applies this to the processing structuring step and then couples this to final product properties. Polymer science and technology is truly multidisciplinary and the staff of the group is comprised of individuals that are all recognized experts in their own field. Projects are supervised and co-supervised by multiple staff members, sometimes even beyond the boundaries of the own (i.e. dr. J.A.W. van Dommelen from Mechanics of Materials. dr. M.F.M Speetjens from Energy Technology, prof. R. Sybesma & dr. J.P.A. Heuts, from Department of Chemical Engineering). Likewise, all staff members are also involved in projects led by other groups often from another Department. It is the groups philosophy to benefit from the broad background of the group members and the combination of our internal expertise leads to direct synergy. The critical mass in the group gives us advantages compared to other more specialized groups. The main research themes are Multiscale Modeling, Computational and Applied Rheology, Polymer Processing and Polymer Mechanics.

The expertise areas of the individual staff members are listed below.

- Mixing and Interfacial Flows: Anderson.
- Rheology and Process Modeling: Peters.
- Multi-scale Analysis & Numerical Methods for the Flow of Complex Fluids: Hulsen.
- Applied Rheology and Flow-induced Structure Development: Cardinaels.
- Multiscale modeling and Nonequilibrium Thermomechanics of Polymeric Systems: Hütter.
- Contact Mechanics and Small Length-scale Mechanical Testing: Van Breemen.
- Structure-Property Relations and Long-term Mechanical Performance: Govaert.

7.3 Major accomplishments in the evaluation period

The Polymer Technology has an excellent track record in previous successive Research Assessments demonstrating almost three decades of excellence. At the end of 2011 the Board of the University appointed prof. Patrick Anderson as full professor and chair of the group. In the last 2014 assessment an average score of 4.8 (on a scale from 1 to 5) was awarded demonstrating, again, the excellent research



The prototype for the Pirouette dilatometer that was commercialised by the TU/e spin-off company IME Technologies.

attitude and research portfolio, that proved to be challenging and interesting for our best MSc students to enter our PhD program.

Our students are very welcome in industry and they usually have multiple job offers before they graduate. In the review period two of our PhD students, i.e. dr. Oleksandr Gorodetskyi and dr. Peter Roozemond, obtained their degree with the judicium Cum Laude, which is relatively rare since on average only five percent of all theses at TU/e are considered for this distinction. To be eligible the PhD work must be of exceptional quality, and must be performed with an exceptional level of autonomy. Two staff members (Anderson & van Breemen) of the group (out of a total of 80 teachers) have been awarded as best teachers within the review period by the BSc and MSc students of the Department of Mechanical Engineering. Since there are only two prizes every year we are proud of this recognition of teaching excellence.

The large number of invitations for plenary, keynote and invited lectures by the staff shows that not only a single member, but all staff members are internationally well recognized. We have a selected number of academic groups with intensified collaboration and mutual visits, i.e. ETH Zurich, KU Leuven, Queen Mary, CalTech, MIT, Napels, Juelich, South Korea. The group itself is also active in the organization of meetings and workshops. In 2013 Anderson chaired the Annual European Society of Rheology AERC2013 meeting (co- chair Van Puyvelde from

KU Leuven) which attracted more than 400 participants and was financially supported by a total of 17 companies in industry, raising 57 k€. Since 2006 Govaert has been successfully chairing the triennial conference on Deformation, Yield and Fracture of Polymers (DYFP), established as the leading event on its subject worldwide. Hütter chaired and was the local organizer of the 7^{th} and 8^{th} International Workshop on Non-equilibrium Thermodynamics in 2015 and 2018 respectively.

Valorization of our work is achieved via the transfer of Intellectual property to industry, also leading to university collaborated patents; several staff members consult for industry. Constitutive models and experimental protocols are adopted by our industrial partners in joint efforts to develop better performing products and new materials. Experimental methods allow for small-scale (micrometers) mechanical testing beyond plastic deformation. The group supports spin-off companies such as IME Technologies, which develops and sells the Pirouette PVT apparatus developed in our group and the electro-spin cabinet. Our in-house developed finite-element TFEM code is on the leading edge in the field of computational rheology and used by other academic (University of Napels, Italy, Goyang-si and Yeungnam University, Korea) and industrial (DSM and SABIC) partners.

Our work on mechanical properties and life-time predictions of polymers is received so well that a number of companies have contacted Govaert directly to start new projects. He is considered the top-expert in this field. The paper 'Mechanical performance of polymer systems: The relation between structure and properties' by Meijer & Govaert, published in Progress in Polymer Science (2010), was listed in the ScienceDirect Top 100 downloaded articles by Netherlands-based authors in physical sciences with 8,766 downloads (2015). In the last lustrum, the group reached significant breakthroughs in the work on Flow-Induced Crystallization of Polymers, i.e. a full experimentally validated crystallization model including detailed structure and phase properties. The experimental work includes some unique set-ups and methods allowing time-resolved structure development measurements.

7.4 Prospects

The continued strong and balanced funding from both the two main sources, NWO-STW and TU/e on one hand and the Dutch Polymer Institute (DPI), EU and industry on the other, provides evidence of the scientific quality and industrial relevance of our research, and warrants a continuous flow of well-educated PhD students with profound knowledge of modeling-based basic research that is broadly applicable to solve real engineering problems. The new Brightlands Materials Center also recognized the existing chain-of-knowledge in the Polymer Technology group and decided to fund a six-PhD program on Additive Manufacturing linking new processing technologies of polymers with final product prop-

erties. The staff members together supervised more than 100 PhD students and our broadly-educated students are very welcome in industry.

The last years there is a new strong trend from large chemical companies that prefer to use combinations of existing well-known polymers and materials to achieve desired product properties instead of synthesizing new polymers. As such, the expertise of the group linking processing of multi-phase flow to properties is of great value. The members of the group react swiftly on new research areas and trends. As such the funding of the group is healthy. The yearly funding has steadily increased from 1.1 M€ up to almost 1.9 M€. Citation analysis shows that the research output is solid and the work is considered relevant.

7.5 Publications, prizes and awards

Key publications in evaluation period

- Roozemond, P.C., Drongelen, van, M., Ma, Z., Hulsen, M.A. & Peters, G.W.M. *Modeling flow-induced crystallization in isotactic polypropylene at high shear rates*. Journal of Rheology, 59, 613-642 (2015).
- Kanters, M.J.W., Kurakawa, T., Govaert, L.E., *Competition between plasticity-controlled and crack-growth controlled failure in static and cyclic fatigue of polymer systems*, Polymer Testing, 50, 101-110 (2016).
- S Krop, HEH Meijer, LCA van Breemen, *Finite element modeling and experimental validation of single-asperity sliding friction of diamond against reinforced and non-filled polycarbonate*, Wear 356, 77-85 (2016).
- Hütter, M., Hulsen, M. A., & Anderson, P. D. *Fluctuating viscoelasticity*. Journal of Non-Newtonian Fluid Mechanics, 256, 42-56 (2018).
- Hejmady, P., Cleven, L., van Breemen, L., Anderson, P., & Cardinaels, R. *A novel experimental setup for in-situ optical and X-ray imaging of laser sintering of polymer particles*. Review of Scientific Instruments, 90(8), [083905] (2019).

Scientific awards and scholarly prizes

- JNNFM and Elsevier Walters award for work Jaensson, N. O., Hulsen, M. A., & Anderson, P. D. (2016). *Direct numerical simulation of particle alignment in viscoelastic fluids*. Journal of Non-Newtonian Fluid Mechanics, 235, 125–142 (2017)
- Distinguished young rheologist award and a TA rheometer voor Ruth Cardinaels (2015)
- Patrick Anderson elected as member-at-large for the Society of Rheology (2015)

- Martien Hulsen receives Highly cited research award from the Journal of non-Newtonian Fluid Mechanics for the paper *Particle motion in square channel flow of a viscoelastic liquid: Migration vs. secondary flows* (2016)
- Runner-up for DPI Golden thesis Award for dr. Nick Jaensson and dr. Monica Zakhari (2016, 2018)

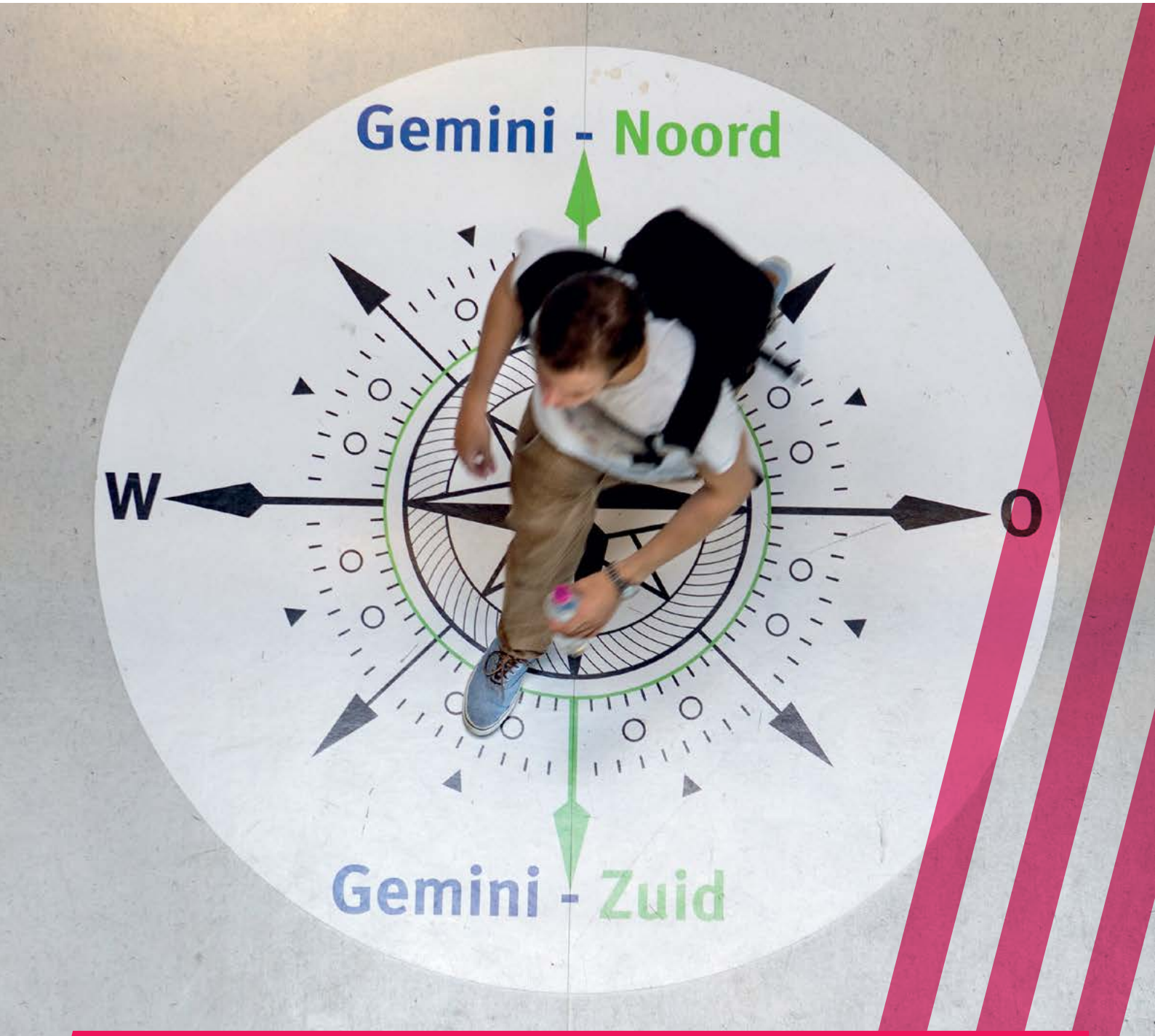
8 Mechanical Engineering TU/e beyond 2020

See the next page.

Department of
Mechanical Engineering

TU/e Technische Universiteit Eindhoven University of Technology

Where innovation starts



Mechanical Engineering @ TU/e beyond 2020

Mechanical Engineering @ TU/e beyond 2020

Background and purpose of this preparatory vision document

What will the Department of Mechanical Engineering of Eindhoven University of Technology look like beyond 2020? On which research themes should we focus? How can and will our scientists work together? These are questions that our Department needs to address in its search for adequate answers to the challenges of the future. Over the course of 2016 we have discussed and answered these questions with experts from our department and experts from scientific institutions and the industry.

This preparatory vision document describes in a concise yet effective manner the outcomes of this extensive thinking process:

- The relevant trends and factors, within the Department and in the outside world;
- The vision on the role of the department;
- A longlist of potential research themes for the period 2020-2030;
- An assessment framework to decide on research themes.

This booklet, therefore, provides the information, vision, and framework that helps the Departmental board to decide on the research themes for 2020-2030. And, in the slipstream of this, the board will decide on the structure of the department. In this way the board will implement the vision into a strategy.

Current structure of the department

The department is currently structured around three main disciplinary pillars (or divisions) on which the research and education within Mechanical Engineering is built:

1. The pillar **ENERGY & FLOW** consists of disciplinary areas related to fluid mechanics, heat transport processes and multi-phase reacting flows. Application areas are related to flow/heat/power equipment such as compressors, combustors, engines, turbines, and process equipment.
2. The pillar **MATERIALS & MECHANICS** consists of disciplinary areas related to (micro) mechanics/fluidics/manufacturing and (multi-scale) materials technology. Application areas are related to important developments in materials technology, automotive, manufacturing and high-tech systems with focus on material processing and performance, microsystems technology, soft and composite materials and failure mechanisms.
3. The pillar **SYSTEMS & CONTROL** consists of disciplinary areas related to dynamical systems, control technology, mechatronics, systems engineering and design. Application areas are related to high-tech systems equipment, automotive systems and mobility, robotics, energy and resource exploration and manufacturing.

Each disciplinary pillar consists of 2-3 sections of variable size. Each section has 1 (to 3) full professors, 3-9 assistant/associate professors and 10-30 PhD students. Sections working in a disciplinary pillar share technical staff and labs.

Current sections within the three pillars:

1a. Multiphase & Reacting Flows (MRF)
1b. Energy Technology & Fluid Dynamics (ETFD)

2a. Mechanics of Materials (MM)
2b. Polymer Technology (PT)
2c. Microsystems (MS)

3a. Control Systems Technology (CST)
3b. Dynamics and Control Technology (DCT)

Novel scientific and industrial developments in the field of Mechanical Engineering urge our department to re-evaluate the existing structure of and current expertise with the department in the light of such developments. Some examples are the focus on extremely small scale (micro and nano) mechanics, which demands new kinds of measurement tools and (multi-scale) modeling tools, but also micro/nano scale design and fabrication techniques. Other examples are the current energy transition, novel additive manufacturing techniques and developments such as industry 4.0, factory-of-the-future, cyber-physical systems, and internet-of-things, and the shift towards more integrated design and control techniques for complex interconnected systems. The required interaction with other fields such as electrical engineering, computer science and data science will increase as well due to the inherent multi-disciplinary nature of the industrial and societal challenges of the near future.

The departmental board wants to make decisions that strengthen the research and education, due to these and other developments foreseen in the future. This means deciding on opening new chairs or changing profiles of existing sections. To enable the board with these tough choices, we embarked on the thinking about “Mechanical Engineering beyond 2020”.

Making of this preparatory vision document

The board asked us, four committed professors, to form the core team to make this preparatory vision document ‘Mechanical Engineering beyond 2020’ The board will use this preparatory vision document to formulate a plan towards a sustainable section/department structure. The Argumentenfabriek, was approached to guide the process. De Argumentenfabriek (The Argumentation Factory) is an independent company that helps organizations come to grips with complex problems by facilitating thinking processes (in so-called Thinking Sessions) and by visualizing information.

Over the period April to September 2016, five Thinking Sessions were held with stakeholders both from within and outside the department/university, including experts from industry. The list of participants is shown in the Table below. In each of the sessions, specific themes were discussed. The Argumentenfabriek, in consultation with our core team, summarized all main discussion points and emerging insights into so-called “maps”. This booklet contains five maps with the outcome of the sessions. The maps follow a logical thinking route. The information contained in the maps reflect the status of September 2016.

1. **EXTERNAL TRENDS AND FACTORS**. This map reflects the most important external trends between 2020 and 2030 that are considered relevant to the department in reformulating its vision for the period beyond 2020.
2. **INTERNAL TRENDS AND FACTORS**. This map describes the most important internal trends between 2020 and 2030 considered relevant to the department in specifying its vision for the period beyond 2020.
3. **VISION ON ROLE**. This map identifies the vision on the role of the department after 2020.
4. **ASSESSMENT FRAMEWORK**. This map represents the assessment framework that the departmental board may use to decide on research themes and structure of the department. The assessment framework helps to decide on research themes for the period beyond 2020 (see longlist in map 5).
5. **LONGLIST WITH REASEARCH THEMES**. This map formulates the ‘longlist’ of possible and current research themes on which the department of Mechanical Engineering of TU/e can focus in the future. These themes were proposed during the sessions by participants both from within and outside the department.

Main conclusions

Many conclusions can be drawn from the large body of results obtained from the sessions. In our opinion, the following observations are standing out.

- A list of 8 **basic disciplines** of mechanical engineering was defined, referring to the eight areas of expertise that collectively form the core of mechanical engineering. All basic disciplines should be represented substantially and visibly in the overall research program of the department, as well as in the educational curriculum. The 8 basic disciplines are:
  - Mechanics
  - Dynamics
  - Thermodynamics
  - Fluid Mechanics
  - Materials Science
  - Systems and Control
  - Design and Construction
  - Manufacturing

The art of mechanical engineering thus lies in the application of design, construction, manufacturing and control principles to mechanical, material and (thermo)dynamical sciences.

- **Scientific excellence** is the most important core value of our research and should be the basis of the department's strategy for the future. Valorization and industrial societal impact are relevant as well, but should follow from the excellent research. This is also the aspect that is valued most by our industrial partners. The department's structure should therefore be based on scientific content rather than application area.
- Connection with the **educational curriculum** is crucial: The department should warrant long-term excellence in education, by connecting to research in all 'basic disciplines' in mechanical engineering (see below).
- **Multi-disciplinary collaboration** is highly relevant. This refers both to collaboration between disciplines within the Department as well as with disciplines in other domains. Hence, research themes that hold potential for collaboration between (mechanical engineering) disciplines should have priority.
- **Design and Construction** was perceived by many of the session participants as an important differentiator for Mechanical Engineering, as compared to other engineering disciplines. The integrating and broad character of mechanical engineering is reflected especially in this basic discipline.
- Choices must now be made – but the existing structure of the department is a solid **backbone** fit for the future.

Next steps

We trust that this preparatory vision document helps the Departmental board with its task to make well-reasoned decisions for the future. On both the research themes and the structure of the Departments and sections.
We thank and all the participants from both inside and outside our department for their commitment and openness in the thinking sessions. And we thank the board for its confidence in us.

The core team

Prof. Jaap den Toonder (chair)
Prof. Nathan van de Wouw
Prof. Maurice Heemels
Prof. David Smeulders

June 2017

Table: Lists of participants in the Thinking Sessions.

Participants from the Department	Participants from outside the Department	Argumentenfabriek moderators
David Smeulders	Akke Suiker (TU/e)	Anouk Mulder
Gerrit Peters	Bendiks-Jan Boersma (TUD)	Maarten Gehem
Hans Kuerten	Carel ten Horn (TATA)	
Hans van Dommelen	Dick van Campen (W)	
Harald van Brummelen	Dirk Smit (Shell)	
Henk Nijmeijer	Ernst Ullersma (Oce)	
Igo Besselink	Erwin Meinders (TNO)	
Jaap den Toonder	Ger Janssen (Philips)	
Jolanda Snelders	Hans Vermeulen (ASML)	
Maarten Steinbuch	Jan Eurlings (Essent)	
Marc Geers	Jelm Franse (ASML)	
Nathan van de Wouw	Markus Bulters (DSM)	
Niels Deen	Niek Lopes Cardoso (TU/e)	
Philip de Goey	Patrick Onck (RUG)	
Regina Luttge	Paulien Herder (TUD/Topsectoren)	
	Richard van de Sanden (DIFFER)	
	Urs Staufer (TUD)	

About the maps that follow

External trends and factors

We started the thinking process with a snapshot of the relevant world around the Department between 2020 and 2030. The first map on page 9 reflects the most important *external* trends (developments) and factors (facts) between 2020 and 2030 that are considered relevant to the department in thinking about its vision for the period beyond 2020. The trends and factors fall into four sections: science, industry, society and technology. The bold sentences reflect the main trends or factors, with the constituting elements underneath. For example, under the section science, one of the main trends identified is: 'Multidisciplinary research is becoming more and more important' (in bold). This is partly so because 'Interdisciplinary and interdepartmental research is demanded due to emerging complex, multidisciplinary themes'.

Internal trends and factors

We also considered the most important *internal* trends and factors – developments and facts that play a role within the TU/e in the period 2020-2030. Here, we identify trends and factors in seven sections: Funding, Organization, Personnel, TU/e Policy, Research, Teaching, and Students. This map can be found on page 10.

Vision on the role of the Department

The map on page 11 identifies the vision on the role of the department after 2020. How does the department view its role as an organization? What about relations with industry? What are the main research goals? What about research content? And finally: what about teaching?

The vision puts special emphasis on what the department calls the 'basic disciplines' of mechanical engineering. This notion refers to the eight areas of expertise that collectively form the core of mechanical engineering, according to the department. These are:

- Mechanics;
- Dynamics;
- Thermodynamics;
- Fluid Mechanics;
- Materials Science;
- Systems and Control;
- Design and Construction;
- Manufacturing.

The vision stipulates that the collective research of the department should cover all basic disciplines. To do so, the department should also provide education in all these basic disciplines.

Assessment framework

The map on page 12 reflects the assessment framework the departmental board uses to decide about future research themes of the department. On the level of *individual* themes, questions relate to scientific relevance and excellence, societal relevance, research collaboration, educational curriculum, strategic match, costs and benefits, industrial research possibilities and reputation. These questions are both relevant for the evaluation of existing and new research themes. For example, when considering a new research theme, it may be relevant to ask: can industry cover this research theme independently (industrial research possibilities)? The same question may be asked for existing research themes.

We also identify questions that might be asked for assessing *the total package* of research themes of the department. The main goal here is to ensure that all basic disciplines of mechanical research are covered, and that fundamental and applied research are approximately equally represented.

Longlist of themes

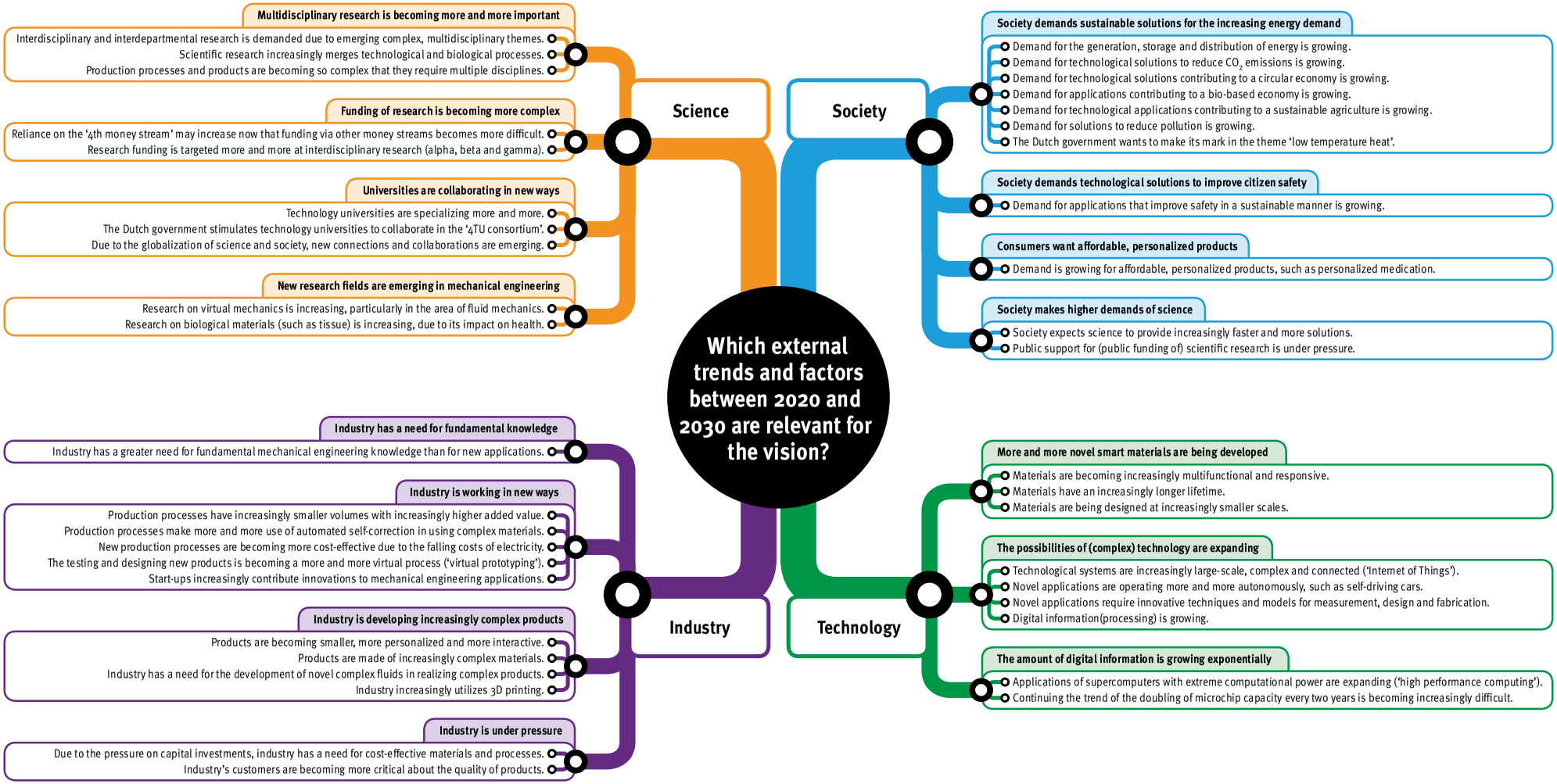
The final map on page 13 demonstrates the 'longlist' of research themes on which the department of Mechanical Engineering of TU/e could focus. The assessment framework on page 12 can help to make choices from the longlist of research themes for the period beyond 2020.

Themes are grouped in the main current research clusters of the department:

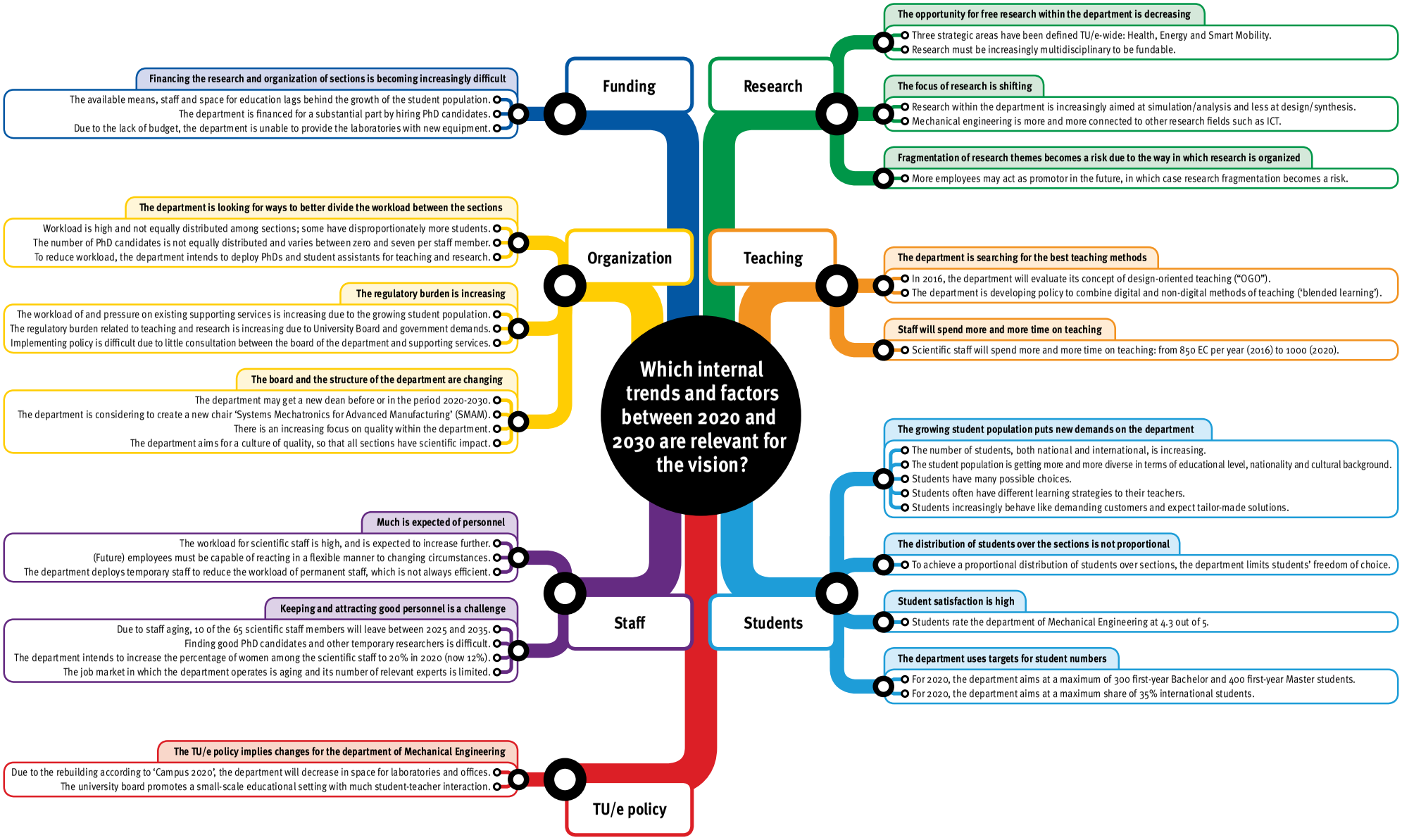
- Energy & Flow;
- Materials & Mechanic;
- System & Control.

Where a theme could not easily be grouped in one of these clusters, we placed the theme under the heading 'Other'.

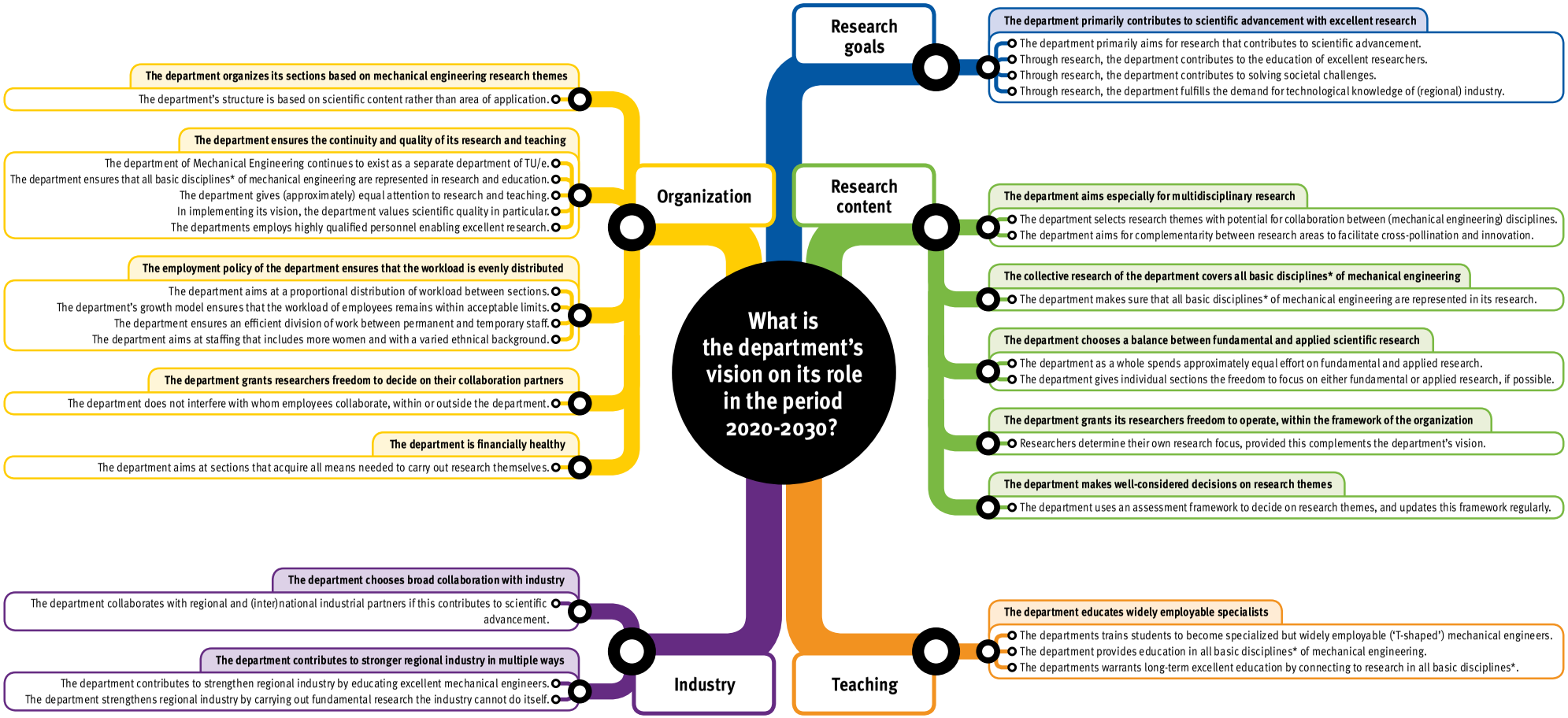
External trends and factors



Internal trends and factors



Vision on the role



*** Basic disciplines of mechanical engineering**
The term 'basic disciplines' refers to the eight areas of expertise that collectively form the core of mechanical engineering, according to the department. These are:

- Mechanics
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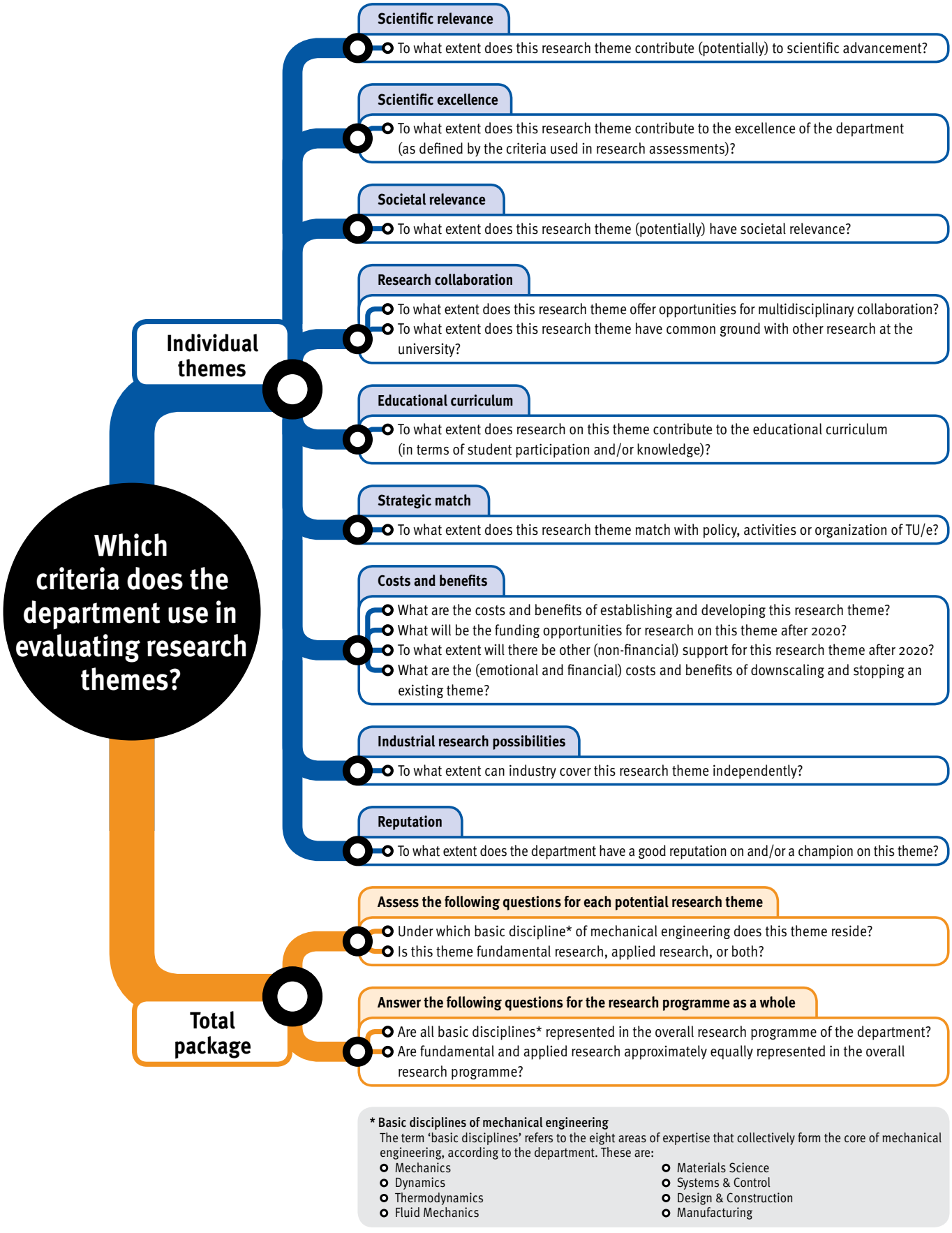
- Fluid Mechanics
- Materials Science
- Systems & Control
- Design & Construction
- Manufacturing

Assessment framework



*** Basic disciplines of mechanical engineering**
The term 'basic disciplines' refers to the eight areas of expertise that collectively form the core of mechanical engineering, according to the department. These are:

- Mechanics
- Dynamics
- Thermodynamics
- Fluid Mechanics
- Materials Science
- Systems & Control
- Design & Construction
- Manufacturing

Longlist with research themes

Icons behind research themes indicate a connection with the cluster in question.
Clearly recognizable existing research themes (2017) are set in bold.
Research themes set in italics indicate that the professor leading this theme will retire around 2020.

Colophon

Coordination: Jaap den Toonder

Cover photo: Bart van Overbeeke

Concept & chart design: The Argumentation Factory

Lay-out & print: Grefo Prepress

9 Engineering Mechanics Research School

See the next page.

Engineering Mechanics Research School

(for further information; see www.engineeringmechanics.nl)

Introduction

Interuniversity research schools have been established in The Netherlands for a variety of scientific disciplines. The Netherlands Research School on Engineering Mechanics (EM) embraces all research groups that are active in the field of Engineering Mechanics at Eindhoven University of Technology, Delft University of Technology and the University of Twente[1]. Together with sister organizations JMBC (fluid mechanics) and DISC (systems and control), the Engineering Mechanics research school covers the general field of mechanics in The Netherlands. EM operates under a formal agreement between the Executive Boards of the participating universities. Eindhoven University of Technology acts as commissioner of EM. EM was founded in 1996 and has received accreditation (1997, 2002, 2007 & 2013) of the National Academy of Arts and Sciences (KNAW) until the nationwide discontinuation of the KNAW-accreditation system in 2014. In the absence of a nationwide accreditation system for interuniversity research schools, it was agreed to evaluate the EM research school within the framework of the research accreditation of the commissioning faculty.

Mission

The mission of the Netherlands Research School on Engineering Mechanics is to ***strengthen academic research and education in the field of engineering mechanics*** in The Netherlands. Thematically, EM covers modelling, analysis and optimization of the static and dynamic behavior of materials, products and mechanical processes.

The mission of EM encompasses the following sub-objectives:

- Administering a training program for PhD-students to support their development towards qualified independent researchers in the field of engineering mechanics according to international standards;
- Coordination and tuning of the engineering mechanics research activities in the participating groups;
- Strengthening of the international scientific position and the international visibility of The Netherlands in the engineering-mechanics field;
- Cooperation with industries and technological institutes to promote the mutual exchange of knowledge on engineering mechanics;
- Connect, cooperate and synchronize with adjacent fields of engineering;
- Promote nation-wide thematic discussions and streamline research agendas with representatives from industry, technological institutes and project leaders to align academic scientific research in the engineering-mechanics field with future needs;
- Guarding the standards of engineering-mechanics research education at the Dutch universities;
- Attracting highly qualified engineers, prospective and established scientists to the Netherlands.

Participants and capacity

The EM research school currently comprises 16 research groups at TUE, TUD and UT; see Table 2 on the next page. With the accession of RUG in 2020, another 2 groups will join EM. The aggregated research capacity in 2018 is summarized in Table 1.

	TU/e (fte)	**TUD** (fte)	**UT** (fte)	**Total** (fte)
Senior academic staff	**18.0**	**17.5**	**18.0**	**53.5**
PhD	**52.0**	**82.0**	**52.0**	**186.0**
Postdocs	**8.0**	**12.0**	**7.0**	**27.0**
Total	**78.0**	**111.5**	**77.0**	**266.5**

Table 1 Aggregated capacity (2018). For research *capacity multiply by 0.8 for PhD/PD, and by 0.4 for staff members.*

[1] In 2020, a new agreement will be established, in which Groningen University will join the EM research school as a full partner.

University	Department	Group, Groupdirector(s)
TU/e	Mechanical Engineering	Dynamics and Control (Prof.dr. H. Nijmeijer) Multiscale Engineering Fluid Dynamics (Prof.dr.ir. E.H. van Brummelen) Mechanics of Materials (Prof.dr.ir. M.G.D. Geers) Microsystems (Prof.dr.ir. J.M.J. den Toonder)
	Built Environment	Applied Mechanics and Design (Prof.dr.ir. A.S.J. Suiker)
TUD	Aerospace Engineering	Aerospace Structures and Computational Mechanics (Prof.dr. C. Bisagni)
	Mechanical, Maritime and Materials Engineering	Structural Optimization and Mechanics (Prof.dr.ir. F. van Keulen) Dynamics of Micro and Nanosystems (Prof.dr. P. Steeneken) Mechatronic System Design (Prof.dr. J. Herder) Biomaterials and Tissue Biomechanics (Prof.dr.ir. A. Zadpoor)
	Civil Engineering and Geosciences	Applied Mechanics (Prof.dr.ir. L.J. Sluys) Structural Mechanics and Dynamics (Prof. dr. A.V. Metrikine)
UT	Engineering Technology	Applied Mechanics (Prof.dr.ir. A.H. van den Boogaard) Dynamics-based Maintenance (Prof.dr.ir T. Tinga) Production Technology (Prof.dr.ir. R. Akkerman) Multiscale Mechanics (Prof.dr.rer.-nat. S. Luding)

Table 2 Participating groups in Engineering Mechanics (2018)

Educational program

The Engineering Mechanics research school administers an educational program of graduate courses, comprised of full courses and topical courses; see Table 3. The study load of the program components is measured in EC, 1EC being equivalent to 2 full days. Full courses pertain to 3EC courses that cover a core area in the field of engineering mechanics. Topical courses are 1EC courses on more specialized subjects. The EM course program follows a 2-year cyclic arrangement, thus enabling each student to participate in each course. Students in the EM school are strongly encouraged to complete a study program of at least 15 EC. The individual study program is set at the student's entry in the PhD program, in mutual agreement between the student and the envisaged promotor. Upon successful completion of his/her 15EC program, the student receives an official certificate from the EM school.

Subject/title	Organizers	Scheduling	EC
Continuum thermodynamics	Turteltaub,	8-9 April 2019	1
Optimization and parameter identification	Langelaar	24-27 May 2019	1
Stability of Structures	van Keulen	13-15 May, 3-5 June 2019	3
Nonlinear Material Mechanics	Van den Boogaard	9-11 Sept. 2019, 16-18 Sept. 2019	3
Solutions methods in computational mechanics	Ten Thije Boonkkamp	5-6 December 2019	1
Solving Structural Acoustic Coupled Problems	Lopez Arteaga	January 2020*	1
Reliability, Lifetime and System Health	Tinga	February/March 2020*	1
Discontinuities, interfaces, fluid-structure interaction and multi-phase problems	Van Brummelen	April 2020*	1,5
Mechanics in Microsystems	Goosen	May 2020*	1
Advanced Dynamics	Alijani	June 2020*	1
Experimental Engineering Mechanics	Hoefnagels	September 2020*	1
Multi-scale and Micromechanics	Geers	November 2020*	3

Table 3 EM course program (2019-2020); see www.engineeringmechanics.nl for course descriptions.

The individual 15EC curriculum should include at least 8 EC from the course program provided by EM. In addition, students can receive credits for external advanced courses, upon prior approval of the director of EM. Recognized external courses are those provided by CISM, GrasMech, JMBC and DISC. Furthermore,

students may follow MSc courses al their host institute, to repair hiatuses in the prior knowledge of the student. The maximum share of MSc courses in a students' EM curriculum cannot exceed 5EC.

The evaluation framework for the EM courses comprises anonymous feedback by the participating students, a reflection by the organizers on the course and the anonymous evaluation, a discussion of improvements with the director of EM, and a course evaluation in the annual board meeting. Since 2018, courses provided by the EM research school are closed with an assessment with a pass/fail grading. Course participants must pass the assessment of a course to receive the allocated credit points.

Auxiliary activities

To stimulate the exchange of information on trends and challenges in research in the field of engineering mechanics, the EM research school organizes an annual 2-day symposium. The program of the symposium is composed of workshops, in which selected PhD students of the research school presents their work in semi-plenary sessions, and poster sessions, in which all students provide an overview of their research project and their recent progress. A central component of the program of the Engineering Mechanics symposium is the *Koiter lecture*, a plenary lecture by a world-leading researcher in the field of engineering mechanics (see https://engineeringmechanics.nl/koiter-lecture-biezeno-award).

Under auspices of the Royal Institute of Engineers (KIVI), the Engineering Mechanics research school organizes and awards the *Biezeno Engineering Mechanics Award*, the annual award for the best PhD thesis in the field of engineering mechanics. The Biezeno Award serves to distinguish outstanding contributions by young researchers in the field.

The EM research school also acts as national point of contact for international organizations in subfields of engineering mechanics. Together with sister organization JMBC, Engineering Mechanics forms the *Netherlands Mechanics Committee*, which acts as the national partner association for international associations such as IUTAM, EuroMech, ECCOMAS and IACM.

Organization

The organizational structure of the Research School on Engineering Mechanics is summarized in the organization chart in Figure 1.

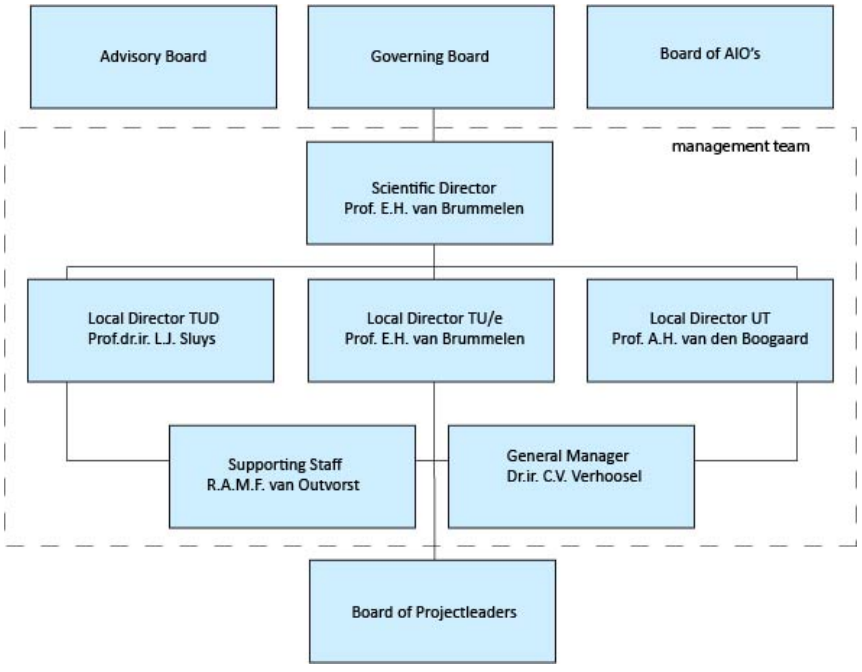


Figure 1 organizational structure of the Research School on Engineering Mechanics

The Scientific Director is in charge of the day-to-day management of the Research School. The Local Directors from the participating Universities assist him in his duties. Eindhoven University of Technology, in its capacity of commissioner of the EM research school, provides additional support for general management and the secretariat.

The Governing Board (see Table for composition) establishes the annual plans on research, education and finances of the Research School. The governing board consults with the board of projects leaders, composed of all staff members of EM, and the board of PhD students, composed of representatives of the students from each of the participating universities. The governing board moreover takes advise from an Advisory Board (see table), which consists of representatives from industry and applied research institutes.

Governing Board
Prof.dr.ir. L.J. Sluys (Chairman, Delft University of Technology)
Prof.dr.ir. F. van Keulen (Delft University of Technology)
Prof.dr.ir. A.H. van den Boogaard (University of Twente)
Prof.dr. ir. A.S.J. Suiker (Eindhoven University of Technology)
Prof.dr.rer.-nat. S. Luding (University of Twente)

Advisory Board
Dr.ir. P. van den Berg (Deltares)
Ir. H.J. ten Hoeve (NLR, Marknesse)
Dr.ir. J. van der Lugt (Tata Steel Research)
Prof.dr.ir. H.M.A. Wijshoff (Océ Technologies B.V.)
Dr. ir. F.J. Blom (NRG Petten)
Ir. H.C.L. Vos (Demcon)

Table 4 Composition of the Governing Board (left) and the Advisory Board (right) of the EM school.

10 Abbrevations

University level

EAISI	Eindhoven Artificial Intelligence Systems Institute university institute
EPC	Equipment and Prototype Centre
ICMS	Institute for Complex Molecular Systems (university institute)
IRES	Institute for Renewable Energy Storage (university institute)
ME	Mechanical Engineering
RSN	Research Support Network
TU/e	Eindhoven University of Technology

Department level

CEM	Computational and Experimental Mechanics (research cluster within dept.)
CST	Control Systems Technology (section within department)
DC	Dynamics and Control (section within department)
DSD	Dynamical Systems Design (research cluster within department)
ET	Energy Technology (section within department)
MoM	Mechanics of Materials (section within department)
MS	Microsystems (section within department)
P&F	Power and Flow (section within department)
POL	Polymer Technology (section within department)
TFE	Thermo Fluids Engineering (research cluster within department)

Research schools

BETA	Research School for Operations Management and Logistics
DISC	Dutch Institute of Systems and Control
EM	Engineering Mechanics
EPL	Eindhoven Polymer Laboratories
JMBC	JM Burgerscentrum (fluid mechanics)
OSPT	Graduate School on Process Technology

Education

AT	Automotive Technology (inter-departmental graduate program)
BKO	University Teaching Qualifications (English abbreviation: UTQ)
BSc	Bachelor of Science
MSc	Master of Science
PD	Post-doc
S&C	Systems & Control (inter-departmental graduate program)
SET	Sustainable Energy Technology (inter-departmental graduate program)
UTQ	University Teaching Qualifications (Dutch abbreviation: BKO)

National

4TU	4TU (alliance of the four Dutch technical universities)
4TU.FSM	Fluid and Solid Mechanics (4TU Research Center)
4TU.HTM	High-Tech Materials (4TU Research Center)
DPI	Dutch Polymer Institute (a LTI)
KNAW	Royal Netherlands Academy of Arts and Sciences
LTI	Leading Technology Institutes
M2I	Materials Innovation Institute (a LTI)
NWA	Nationale Wetenschapsagenda
NWO	Netherlands Organisation for Scientific Research
TNO	Netherlands Organisation for Applied Scientific Research
TTI	Leading Technology Institutes (Dutch abbreviation of LTI)
TUD	Delft University of Technology (Dutch technical university)
UT	University of Twente (Dutch technical university)
WUR	Wageningen University and Research (Dutch technical university)

International

ERC	European Research Council

11 Appointment regulations

See the next page.

Appointment procedures for full professors, associate professors and fellows

A new protocol was adopted by the Executive Board in September 2017. The Personnel Policy for Academic Staff 'Excellent People Attract Excellent People - the next generation' is used as a starting point for the development of academic careers. In order to avoid duplication, this protocol refers where possible to the Development Track Regulation, as adopted by the Executive Board on 21 September 2017.

Administrative framework

Pursuant to Article 2.19 of the TU/e Administration and Management Regulations, the Departmental Board (FB) adopts the Departmental Chair and Associate Professors (UHD) plan and the Executive Board (CvB) approves Departmental Chair and UHD plans and the amendments thereto. The CvB also appoints full professors and UHDs on the recommendation of the FB. The same applies to the promotion of UHD-2 to UHD-1 and of Full Professor 2 to Full Professor 1. The evaluation of proposals will be based on the UFO classification criteria and the Faculty matrix as set out in the Personnel policy. As of September 2017, Deans may, on behalf of their department, nominate UHD-1s in possession of a doctorate (who they consider qualified to act as supervisor) to the Doctorate Board (CvP) prior to or at the start of the first PhD trajectory in which they will act as supervisor.

Types of professors and fellows

Within the TU/e, we make a distinction between full-time professor, part-time professor, university professor and endowed chairs. In addition, at TU/e valorization is unmistakably a distinctive feature of its DNA and TU/e is committed to strategic cooperation with the business community. TU/e and Departmental Fellows play a prominent role in this. They provide the connection to the outside world.

Full-time professor

A professor excels in a certain subject area and is responsible for a strategic area, with a commitment in education and research and is appointed for an indefinite period of time.

Part-time professor

A part-time professor is a professor who has his/her main appointment outside the TU/e. Within the TU/e he/she is employed for a maximum of 0.4 FTEs. The part-time professor has a commitment, focused on a specific expertise, for example a specific application area. A part-time professor is linked to a full-time professor within one of the department's research areas.

Distinguished University Professor

Distinguished University chairs are set up to retain top scientists working at the TU/e or to connect top scientists from outside to the TU/e. They act as ambassadors of the institution. Distinguished university professors are attached to a department. The department pays the salary. For a period of five years, the CvB pays a supplement to the salary and may also provide additional resources. The distinguished university chair is subject to specific criteria and a separate appointment procedure. The Distinguished University Chairs Regulations are included in Annex D.

Endowed chair [1]
The management board of a legal entity wishing to establish an endowed chair at the university should send such a request to the CvB. The TU/e only allows endowed chairs on an ideological basis. The endowed chair is appointed by the legal entity, not the TU/e. The endowed chair does not have to be included in the curriculum of a department. In the case of new occupiers of these chairs, the first appointment shall be for a period of three years. The subsequent appointment can then be made for a longer period (five years) for this category of professors, in consultation with the foundation in question. In exceptional cases, a second reappointment that is duly substantiated by the foundation in question, may be requested.

Distinguished professor
The TU/e encourages and nurtures collaborative relationships between its scientific staff and international top professors and their research groups. In this context, the possibility has been created to offer top professors with whom a relationship is sought and/or maintained, a position as Distinguished Professor for four years. Distinguished Professors spend one week a year at the TU/e and then give lectures for the academic staff, PhD students and selected master students and are also available for consultation with staff members about important developments in their field.

TU/e and Departmental Fellow
The TU/e and Departmental Fellowship are intended to connect leaders from a specific field of expertise to the TU/e, but who do not have the scientific knowledge and/or experience that a Full Professor or UHD can be expected to have. TU/e and Departmental Fellows function respectively at the equivalent level of Full Professor and UHD and act as ambassadors for the TU/e. Based on the nature of their careers, they work particularly in the field of Valorization. They also actively contribute to scientific research and education. This could include people with a special track record of R&D responsibility in a particular area in the business community. For the appointment as fellow, the Procedure for appointment as a TU/e and Departmental Fellow applies, which is attached as Annex E.

Origin of professorships and UHD positions
The inflow of UHDs and full professors can take place in two ways: through open recruitment at the moment of a vacancy, or through further growth within the TU/e of a talented assistant professor (UD) or UHD on the basis of a Development Track.

If the FB wishes to fill a vacancy for a full professor or UHD, the FB will inform the CvB in writing via the CvP. This information is accompanied by a description of the position and the organizational context within which the function in question must be performed (profile sketch). The criteria applicable in the discipline for the domains Research, Education, Valorization and Organization (OOVO) are mentioned. The FB also makes a proposal for the composition of the Advisory Committee on Appointments (BAC).

If the UHD or full professor's position arises after a Development Track has been completed, the CV of the candidate in question is also added and the CvB is asked to refrain from open recruitment.

Once the profile and composition of the BAC have been approved by the CvB, the recruitment and selection process or the assessment process is started.

[1] Art. 9.53 WHW and Chapter IV Administration and Management Regulations TU/e

Procedure
During the open recruitment procedure, candidates are proactively scouted and the shortlist at the end of the recruitment process is made up of at least one third of women.

For an appointment of external candidates as a UHD, full professor and fellow, advice should be sought from a Recruitment Advisory Committee (R-BAC). For internal candidates, advice is sought from a Promotion Assessment Committee (P-BAC). Promotion within the post to UHD-1 or Full professor 1 takes place by seeking advice from a departmental committee. The requirements for the composition of a R-BAC and P-BAC and the process to be followed are described in the Development Track Regulation.

The composition of the departmental committee is:
- At least 3 full professors and/or UHDs
- Program Director
- 2 IFC members from own department
- HR advisor (secretary)
- Supervisor (informant)

Nomination
In the case of external recruitment for a position as a UHD or full professor, 1 female and 1 male candidate must be proposed by the FB for assessment by the R-BAC. In its final recommendation, the R-BAC advises the FB which candidate is preferred. If this advice is not adopted by the FB, the Dean will give reasons for this to the rector. This motivation will be included in the nomination submitted to the CvB.

The FB shall submit nominations to the CvB for appointment as Full professor or UHD, or promotion to UHD-1 or Full professor 1, by submitting the advice of the R-BAC or P-BAC. The CvB will seek the advice of the CvP in this respect.

The following documents must be provided in the case of a nomination for appointment:

- advice from the R-BAC or P-BAC
- CV incl. publication list of the intended candidate (see Annex A)
- research statement of the intended candidate (max. 1A4)
- teaching statement of the intended candidate (max. 1A4)
- profile sketch
- motivation of the FB (max. 1A4)

Annex B discusses the assessment criteria for the appointment of full professors and UHDs within the field of design.

Appointment
After consulting the Doctorate Board, the Executive Board decides on the appointment of a UHD, full professor or fellow.

The term of a part-time UHD or part-time full professor is in principle five years. There is no automatic entitlement to an extension.

The options for part-time appointments are as follows:

1. Preferably a NOP (Not On Payroll) employment contract or an unremunerated employment contract (on the basis of a secondment from another university/business and/or without an underlying legal basis for payment, e. g. the person concerned performs the work as a part-time UHD or part-time full professor 'gratis').
2. A one-time employment contract for five years pursuant to article 2.2a of the Collective Labor Agreement for Dutch Universities in which a reappointment for a second term on the same basis is not present.
3. If, in the case of a specific reappointment after an initial term with a legal basis of 1) or 2) a department proposes to appoint either a part-time UHD or part-time full professorship on the basis of a TU/e employment contract for an indefinite period, or to appoint for a second term of a different duration (i. e. other than 5 years) on the basis of 1), the nomination for reappointment submitted to the CvP should expressly set out the arguments/reasoning/ underlying basis for the departure from 1) and 2). The procedure for reappointment is set out in Annex C.

Granting Ius Promovendi

The right to act as supervisor or Ius Promovendi is granted automatically when appointed as full professor. As of 1 September 2017 the law offers the possibility for other doctorate-holding members of staff, in addition to professors, to act as supervisors. At TU/e it has been decided the Ius Promovendi might be granted to associate professors (UHD), when they have proved to supervise PhD candidates in a capable manner. It is not a self-evident right. This is also stipulated in The Doctorate Regulations as of 1 September 2018.

A UHD has qualified as a capable supervisor of PhD candidates, when:

- The UHD has adequate experience in the independent supervision of PhD candidates and in successfully completing the PhD trajectory.
- The UHD is or has been responsible for independent projects including funding.

Departments may add other criteria.

Granting the ius promovendi to UHD's can be assessed at different moments:

1. If someone is directly appointed UHD or if an internal candidate is up for promotion to UHD2 the department board asks an R-BAC resp. P-BAC also to advise if the candidate should be given Ius Promovendi
2. In the case where there is no direct promotion or appointment the department board can ask a departmental committee to advise if a candidate should be given Ius Promovendi. The departmental committee should include two members of an IFC that belong to the department.

The advice of the BAC or departmental committee is submitted to the Doctorate Board for appraisal, which decides if Ius Promovendi is granted.

At the beginning of the doctorate trajectory it must be clear who the intended supervisor(s) is/are. For ongoing doctorate trajectories where a UHD already effectively leads the project, the formal promotorship can be changed, provided that dean, professor and UHD all agree. In this case a revised Form 2 needs to be sent the Office of Doctoral Presentations and Academic Ceremonies (P&P), in which is explicitly mentioned that the composition of the supervision team has changed.

Finally
Deviations from these procedures are only possible subject to prior agreement in the Doctorate Board.

Executive Board, 18 June 2018

Annexes

A. Curriculum vitae requirements:

- Personalia, incl. date of birth
- Training
- Professional career path, incl. sabbatical leave, international experience etc.
- Awards, nominations and honours
- Funding granted (role (PI, team member, etc), project, type of funding, period, budget)
- Educational activities (BKO, designing, teaching, evaluations)
- Supervision of PhD, PDEng, MSc and BSc students
- Research activities (committees, memberships, reviewing roles)
- Publication list (5 key publications, theses, peer-reviewed journals, refereed conferences, books, book contributions, professional journals)
- Presentations (key-note speeches, presentations, etc.)
- If applicable: portfolio description of the design oeuvre
- Language competence
- Referees
- Use of academic results in society
- Information showing that the level of the candidate has been demonstrated outside the TU/e and in competition

B. Evaluation criteria for the appointment of design-focused full professors
Design-focused full professors and UHDs who are unable to provide evidence of their scientific excellence - PhD and international scientific publications - but who meet the portfolio requirements of designers, may be appointed on a part-time basis.

In 1999 a VSNU working group, chaired by H. G. Stassen (TUD), issued the advice 'Evaluation Criteria for Design Disciplines'. This advice has been adopted.

The VSNU working group has based its assessment criteria on the following criteria: quality, productivity, relevance, and viability. These are specifically filled in for designers as: design quality, production expressed in the work, design relevance and social relevance, including economic usefulness and applicability. In the meantime, the criteria Research Quality, Social Relevance and Viability have been applied in the Standard Evaluation Protocol 2015-2021.

The following points will be taken into consideration when assessing the design-focused candidate full professor or UHD:

- novelty in relation to the state of the art, originality
- design methodical approach with reasoned subjectivity
- construction and materialization in practice, if applicable
- evaluation of the actual performance of the design compared with the intended performance
- integration of design, development and research
- Integration of designs at different scales (vertical)
- Integration of partial designs and sub-aspects (horizontal)

- vision of future development of the design, subject and scientific fields covered by the program
- design assignments, preconditions and realizations of designs, inventions and patents
- craftsmanship, practicality, technical ingenuity

The R-BAC should use the above criteria. [This shall be stated in the advertisement.] Its opinion will be submitted to the CvB. The advice of the R-BAC is accompanied by the written opinions of at least three referees. Half of the referees consist of professors from universities abroad in the same discipline as the candidate. The other half is made up of leading practitioners. Design-focused full professors are expected to profile themselves regularly with a scientific publication in their domain. In the event of reappointment, this will be part of the assessment.

C. Reappointment of part-time professors and part-time UHDs

A request for reappointment must be submitted to the CvB at least 4 months before the term of appointment expires. If such a request is not received in due time, the person concerned shall be informed three months before the expiry of the current term of appointment that the employment contract is terminated. The CvB seeks the opinion of the CvP on reappointment.

The request for a first reappointment (second term) has to be based on the written assessment of the documents by a departmental committee, advising the department board. If the department wishes to nominate the part-time professor or part-time UHD for a second reappointment (third term), a meeting of a P-BAC including a presentation by the candidate has to take place, after which the P-BAC sends its advice to the department board. When new requests for reappointment follow, this will alternately be based on a written assessment and on a meeting of a P-BAC.

The following documents are part of the request for reappointment of a part-time professor or part-time UHD:

- Accompanying letter signed by the Dean and managing director of the department concerned
- Motivation by the department board (maximum 1 A4) stating whether the person concerned has a position elsewhere which is considered essential for the contribution to scientific education and research
- Updated CV of the person concerned meeting the requirements as set out in Annex A
- Activity report for the current appointment period, clearly identifying TU/e-related activities. The report shall include further information on
  a. projects (including second-flow and third-flow funding);
  b. publications;
  c. the education provided;
  d. the supervision of MSc, PDEng and PhD students
- Work plan for the period ahead (maximum 1 A4).

D. Distinguished University Chairs Regulations

Distinguished university chairs are established to retain top scientists working at the TU/e or to connect top scientists from outside to the TU/e. They act as ambassadors of the institution. Distinguished university professors are attached to a department. The department pays the salary.

The CvB pays a supplement on top of the salary for a period of five years and may also make additional resources available. The distinguished university chair is subject to specific criteria and a separate appointment procedure.

a. Appointment
Distinguished university professors are appointed for a period of five years. Extensions of five years are possible.

b. Profile
The distinguished university chair does not necessarily have to be linked to a specific commitment. The CvB, in consultation with the CvP, may decide to assign a distinguished university professor the task to (further) develop a new area or to entrust him/her with another task for the benefit of the institution.

c. Criteria
Full professors who are eligible for a distinguished university chair must meet one or more of the following conditions in addition to the relevant criteria for full professors:

- Very high scores in citations and research evaluations.
- Very high quality projects with second-flow and/or third-flow funding.
- Very prestigious international research awards or other awards.
- Stand-out achievements in other areas relevant to the TU/e such as education, valorization or outreach.

d. Appointment procedure
Each Dean may submit an argued nomination of a candidate to the CvP. The CvB may also nominate a candidate. Candidates should have the broad support of the CvP.

E. Appointment procedure to TU/e- and Departmental Fellow

The TU/e and Departmental Fellowship are intended to connect leaders from a specific field of expertise to the TU/e. TU/e and Departmental Fellows function at the level of Full professor and UHD respectively and act as ambassadors for the TU/e. From the nature of their careers, they emphatically perform in the field of Valorization (Faculty matrix; Personnel policy). They also actively contribute to scientific research and education. This could include people with a special track record of R&D responsibility in a particular area in the business community.

a. Profile
TU/e and Departmental Fellows are characterized by the following profile:

- image and stature, evidenced by e. g. patents, trademarks, lectures and/or prizes and the judgment of experts
- top expert in his/her field of expertise and widely recognized as such
- ability to acquire funds and/or
- ability to develop new fields of education or research

The TU/e and Departmental Fellows are expected, in collaboration with the scientific staff, to:

- initiate and promote sustainable cooperation with the business community and government
- carry out the relevance of science and represent the TU/e in this
- promote and support spin-offs

- generate second-flow and third-flow funding for research projects and/or
- acquire contract education
- make science accessible to the wider public
- actively participate in and influence public debate
- ensure a link between education and the business world and hence develop and provide innovative, substantive contributions within the educational curriculum of the discipline.

In addition, the TU/e Fellow is expected to:

- be an authority, deliver output and have an impact at international level
- in collaboration with the full professors within the discipline, develop a vision and valorization policy and create an environment in which valorization is recognized and promoted.

b. Procedure

Both the CvB and the FBs have the opportunity to make argued proposals for appointment. Advice on this is sought from a Recruitment Advisory Committee (R-BAC). The appointment procedure for a Departmental Fellow is the same as for a UHD appointment. The appointment procedure for a TU/e-Fellow is the same as for a Full Professor. (See Development Track Regulation)
Appointment will be made by the CvB, following a positive recommendation from the CvP. The profile description should indicate which result agreements will be made with the candidate.

Appointments are made temporarily for a period of five years on the basis of an unremunerated employment contract based on a secondment. At the end of the appointment period, the performance agreements will be evaluated. Pursuant to article 2.2a of the Collective Labor Agreement for Dutch Universities, a one-time employment contract of 5 years may be awarded.

At the end of the temporary appointment, a subsequent reappointment is possible if the fellowship is unpaid on the basis of secondment.

c. Description of Fellowship

The title of 'Fellow' title will be used in combination with the discipline:
Departmental Fellow: Fellow <discipline>
TU/e Fellow: TU/e Fellow <discipline>

In order to promote strategic cooperation with the business community, an appointment of a TU/e and Departmental Fellow will be publicized.

12 Position paper TU/e Graduate School

See the next page.

Training and development of PhD candidates at the TU/e Graduate School

Position paper

***PhD Steering Committee*[1]**

Introduction

One of the primary tasks of our University is to provide PhD candidates[2] with excellent training, education and supervision, in order to prepare them for a future career as research professional. This takes place at the interface between research and education: PhD candidates become research professionals while doing research under the guidance of qualified researchers. Recently Doctoral (PhD) programs[3] at the TU/e have been brought under the umbrella of the Graduate School, together with Master (MSc) and Designer (PDEng) programs. There are 15 discipline-based Graduate Programs that are internationally recognizable. This position paper is intended to serve as the basis for a rethinking of the structure of the PhD programs in order to foster and further ensure excellent quality, now and in the future.

The selection of the position statements to restructure the PhD programs presented in this position paper was prepared by a Steering Committee that was asked by the Dean of the Graduate School for advice with regard to PhD training and development. In order to prepare this paper, a preliminary version[4] was broadly discussed with faculty and PhD candidates from all departments as well as with other stakeholders such as directors of Research Schools, the TU/e PhD Council and support staff (research policy advisors and HR professionals)[5].

The rationale for the statements reflects the needs of PhD candidates as well as of their (co-) supervisors. The general idea behind rethinking the PhD programs is to maintain what is good, improving what needs to be improved, while still allowing for the discipline-related variety in specific Graduate Programs. Before presenting the proposed position statements, Section 1 gives an overview of current practice and future developments with regard to PhD education, followed by the vision of the TU/e Graduate School that underlies all Graduate Programs, as outlined in Section 2.

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[1] Members PhD Steering Committee: Prof.dr.ir. J.C. Fransoo (chair; Dean Graduate School and Professor IE&IS, Prof.dr.ir. P.D. Anderson (Professor M, scientific director research school EPL), Prof.dr.ir. W.M.M. Kessels (Professor AP), Prof.dr. J.S.H. van Leeuwaarden (Professor M&CS), Prof.dr. E.W. Meijer (Professor BMT and CE&C), Prof.dr. H.J.P. Timmermans (Professor BE), Drs. N.H.M.G.A. van der Wolk (Director DPO), ir. K. Kompatscher, PhD candidate (BE), Ir. K.A Buist, PhD candidate (CE&C), Ir. S.W.F. Jansen, PhD candidate (IE&IS), supported by Dr. D.M. de Haan (STU), Mr.drs. B.C. Donders, Dr. E. Appelo (DAZ).

[2] Because of the entwinement of education and the research process at the TU/e, we prefer the term "PhD candidates" rather than "PhD students."

[3] The term "PhD program" is used here as a very general term to describe the process of obtaining a PhD; it does not necessarily entail a program in the form of courses or a curriculum, as the traditions in the different disciplines on campus are very diverse.

[4] See: https://static.intranet.tue.nl/uploads/media/Discussion_paper_PhD_education_03.pdf

[5] See: https://intranet.tue.nl/onderwijs/tue-graduate-school/phd/timing/

1. Current practices and future developments

The quality of the PhD training at the TU/e is currently regarded to be of a high international standard[6]. The average duration of the PhD trajectories of 4.5 years is among the shortest in the Netherlands[7]; the average drop-out rate of 20% is among the lowest in the Netherlands[8], although it is higher than international benchmarks; and the satisfaction of PhD candidates is also generally very high. The outcome of a recent survey on the doctoral climate[9] revealed an overall high level of satisfaction of the PhD candidates with the supervision of both the supervisor (86%) and the co-supervisor[10] (91%). In addition, 70% of the PhD candidates rated their program as equal to 8 or higher (out of 10). Some points of attention include difficulties with finding information on certain disciplinary courses (41%), and the practical use of a Training and Supervision Plan (TSP).

There are, however, several developments that should be taken into account to ensure the TU/e remains attractive to prospective PhD candidates and to maintain the high quality of the PhD training in the future.

First, the recent DPO inventory shows that the population of PhD candidates at TU/e is changing. There is a growing number of international candidates. There is also a growing number of candidates who are not on the payroll of the University; they bring their own scholarship, are employed by industry, or conduct their PhD research under other employment conditions.

Second, the TU/e PhD Satisfaction Survey revealed that about 65% of the respondents did not expect their next career step to be in academia. Many of them (41%) expect to obtain an industrial research job. A CBS study[11] (2014) of PhD graduates confirmed the realism of this expectation. In spring 2014, over 85% of TU/e PhD graduates were involved in research and development roles, but most of them outside academia, for example, in consultancy and industry. For TU/e graduates this pattern has been stable over time; there are no differences in career between earlier and recent PhD graduates.

Given these findings, and taking into account a recent advice of the KNAW[12], career orientation should explicitly get attention during the PhD trajectory.

2. Vision of TU/e Graduate School on PhD training and development

It is the mission of the Graduate School to educate graduates who are prepared for a successful start to their career in a broad range of sectors (from high-tech industry and the academic world to the

[6] Source: SEP-based research assessments of TU/e research programs
[7] Source VSNU Facts and Figures, 2015
[8] Source: DPO, Inventory of PhD registration and drop-out
[9] Source: PhD Satisfaction Survey, DPO/STU, 2015
[10] We use “supervisor” and “co-supervisor” as official English translations for the Dutch terms *promotor* and *co-promotor*. They can also be seen as synonyms for “advisor” and “co-advisor” as used in the US.
[11] CBS: “Rapport Gepromoveerdenonderzoek 2014: gepromoveerden, carrière en mobiliteit TU Eindhoven.”
[12] https://www.knaw.nl/nl/actueel/nieuws/promoveren-werkt, 2016

service sector, education and government) and in an international context. In line with this mission, all graduate education is characterized by a strong emphasis on:

- high quality;
- personal coaching and guidance (master-apprentice model);
- freedom of choice;
- international orientation;
- career orientation;
- attention to the development of social and academic skills;
- strong relationship between research and education;
- sense of community.

The Graduate School offers programs for PhD candidates that are structured to ensure that we deliver excellent graduates who find positions on the academic and non-academic labor market, with a low drop-out rate (our ambition is max. 10%, preferably concentrated in the first year) and within four years for fulltime PhD candidates. In line with the KNAW, the TU/e considers that the excellent quality of PhD degrees awarded by Dutch institutions in general can partly be attributed to the length of the PhD track, which is typically four years. A shortening of the PhD trajectory will only be possible for a group of very highly qualified students who are able to combine their MSc with a preparatory trajectory on top of their master program. This might, for example, be realized by combining the MSc program with an honors track.

Although the number of PhD candidates who bring their own funding and/or are not on the payroll of the University is growing, the majority of TU/e's PhD candidates will be appointed as an employee, in line with the current policies and the KNAW's recommendation. Nevertheless, even if they are not directly employed by the University, all PhD candidates are considered equivalent to employees in terms of their daily tasks: they are entitled to the same privileges and have the same duties.

For discipline-specific education, TU/e values the role of the national Research Schools, which offer excellent opportunities for PhD candidates to develop disciplinary skills through courses of high standard. They also offer the opportunity for candidates to build their own national disciplinary networks.

3. Position statements

This section discusses the position statements that capture the key characteristics of PhD programs at the TU/e. Where necessary some clarifying remarks are added based on the questions and remarks that have been collected in the earlier mentioned discussion round. An overview of the nine position statements is presented in Table 1. Each statement is discussed in more detail in order to provide an impetus to design more practical procedures and processes.

A. **The objective of the TU/e PhD trajectory**	*The TU/e Graduate School offers personalized, on-the-job PhD training under the supervision of qualified researchers, with the aim to educate qualified and independent research professionals. This is demonstrated through a dissertation or technological design and its public defense at the end of the PhD trajectory.*
B. PhD candidates	*All PhD candidates, whether on the TU/e payroll or not, have the same rights, duties and responsibilities.*
C. PhD (co-)supervisors	*(Co-)Supervisors are committed to the TU/e PhD training principles and to facilitate the development of the PhD candidates.*
D. Research Schools	*Disciplinary courses are primary offered through Research Schools or similar inter-university networks.*
E. Admission and selection	*The TU/e admission and selection procedure aims at selecting the best PhD candidates and ensuring the successful completion of the PhD trajectory for all involved.*
F. Monitoring PhD trajectories	*The TU/e Graduate School has monitoring procedures to efficiently reduce (late) drop-out and delay, and pursues graduation on time, based on the PhD registration and monitoring system.*
G. Graduation	*The TU/e has sound regulations that guarantee the quality of the conferred degree and facilitates a smooth administrative procedure.*
H. Role of the Graduate School	*The TU/e Graduate School facilitates PhD candidates and (co-)supervisors in achieving high quality PhD trajectories.*
I. Quality assurance	*A quality assurance system is in place at all levels.*

Table 1: Position statements for PhD-centered training and development at the TU/e Graduate School

A. The objective of the TU/e PhD trajectory

The TU/e Graduate School offers personalized, on-the-job PhD training under the supervision of qualified researchers, with the aim to educate qualified and independent research professionals. This is demonstrated through a dissertation or technological design and its public defense at the end of the PhD trajectory.

1. A PhD graduate is able to start a successful career in a broad range of sectors (from high-tech industry and academia to the service sector, education and government) and in an international context. As such, a PhD graduate:[13]
    a. *has made an original contribution to academic research of a quality which stands up to peer review at the levels expected in the Netherlands; .*
    b. *has demonstrated his/her ability to apply the academic methods used in the discipline concerned to develop, interpret and apply new knowledge;*
    c. *has acquired and worked with a substantial body of knowledge in his/her field of expertise;*
    d. *has developed the transferable skills that are needed to work in different research environments;*
    e. *is able to exercise social responsibility in conducting, and applying his/her own research;*
    f. *is able to transfer knowledge in a teaching environment.*
2. During the PhD trajectory, a PhD candidate must perform research within the context of one of the Graduate Programs, resulting in a dissertation or technological design.
3. Each PhD candidate at TU/e is supervised by two or three persons (one or two supervisors and/or one or two co-supervisors) , in most cases supervision takes place by one supervisor and one co-supervisor.
4. The PhD candidate is stimulated to participate in the research community of his/her (co-) supervisors.
5. Each PhD candidate follows a program that generally includes the development of research skills, teaching skills, transferable skills and disciplinary skills. The actual program of each PhD candidate is tailored to his/her specific needs and future career ambitions. Each Graduate Program may require the completion of a specific training with a maximum of 30 ECTS.[14] These can include courses given by various Research Schools if approved by the Graduate Program. The Graduate School does not prescribe minimum university-wide requirements on the actual content of the training program, with the exception of a mandatory introduction session that includes training on scientific integrity.
6. As research professionals, all PhD graduates are able to transfer their knowledge. The TU/e sees teaching as a valuable way to develop these skills. During the PhD trajectory, every PhD candidate is expected to spend a minimum of 10% of the overall workload on teaching tasks (with an annual workload of max. 15%).
7. The PhD degree is awarded by a committee of peers (the Doctorate Committee) on behalf of the Doctorate Board based on the quality of the dissertation or the technological design and the defense by the PhD candidate.

[13] Based on VSNU (Hora Est, 2004).

[14] The ECTS credit system is based on the time invested in completing a program (1 ECTS = 28 hours of study). At TU/e it can also be applied to an estimation of time for workshops, summer schools, etc., which are usually not calculated in ECTS.

Remarks

- *"On-the-job" means that the development of PhD candidates into independent researchers takes place while they are doing research. The personal coaching and guidance by the (co-)supervisor, in a so-called master-apprentice model, takes place on-the-job and is supported by other means of training and education.*
- *"Research professional": the TU/e deliberately uses this term in a broader sense than "academic researcher." Most of our PhD candidates do not embark on an academic career. Therefore, the TU/e pays particular attention to career preparation outside academia, which is facilitated by the Graduate School.*
- *"Transferable skills" are defined by the European Commission as "… skills learned in one context (for instance research) that are useful in another (for example future employment whether that is in research, business, etc.). Examples include interpersonal skills, organizational skills, communication skills, and entrepreneurial skills".*[15]
- *Transferable skills are currently offered primarily through the PROOF program.*
- *Teaching tasks include lecturing, practicum assistance, tutoring, mentoring/coaching, and/or supervision of MSc/BSc students during their final project. By setting both a minimum overall and an annual maximum teaching load, it is possible to concentrate the teaching tasks in specific periods within the nominal period for a PhD trajectory.*
- *If teaching tasks extend beyond the borders of the research group to which the PhD candidate belongs they have to contribute to the development of the PhD candidate.*
- *PhD candidates should be well equipped to fulfill their teaching tasks; a specific training program might be needed.*[16] *Teaching skills can be developed as part of the PROOF program or as part of the programs of the Eindhoven School of Education. The latter might be particularly relevant if PhD candidates are interested in obtaining a high school teaching qualification.*
- *Research and disciplinary courses are usually offered by the Research Schools and PhD training networks: in some disciplines, these primarily require participation in Summer Schools or similar events. Specific disciplinary courses offered in MSc programs are also of interest. Currently, PhD candidates have difficulties finding information on these courses*[17]*. More support, coordinated by the Graduate School, is foreseen.*
- *To cover different future career perspectives, a Graduate Program might consider different profiles; for instance, teaching, academic research, industrial development and entrepreneurship.*

B. PhD candidates

All PhD candidates, whether on the TU/e payroll or not, have the same rights, duties and responsibilities.

1. All PhD candidates have access to the same facilities, including, but not limited to, courses, conference participation and research facilities. This includes PhD candidates who are not on the payroll of the University (NOP), but who are conducting research with the primary aim of graduating based on the equivalent of a 0.8-1.0 FTE contract.

[15] Source: "Innovative doctoral training at universities of science and technology," 2015
[16] See: ISO/PNN, De promovendus als docent (2016)
[17] Source: PhD Satisfaction Survey, DPO/STU, 2015

2. Agreements between the PhD candidate and his/her (co-)supervisors about the research, the content of the training program (including measures to address deficiencies, such as, for example, in communication skills), teaching tasks, and the way supervision is provided are laid down in the Training and Supervision Plan (TSP) produced by the PhD candidate.
3. During the PhD trajectory, the PhD candidate has the obligation to submit progress information according to the deadlines agreed within the TSP.
4. All PhD candidates act according to the code of conduct with regard to scientific integrity.
5. The rights, duties and responsibilities of PhD candidates of the TU/e Graduate School may be published in more detail in a charter.

Remarks

- *For PhD candidates who are not employed at TU/e, but have for example a scholarship, special attention is needed to ensure that a budget for education and supervision is guaranteed. In general, TU/e charges a bench fee/tuition fee to cover these costs.*
- *For PhD candidates who are employed by industry, the contract should cover arrangements that ensure that they are entitled to the same rights, and have the same duties and responsibilities as PhD candidates that are employed by the TU/e (for example, to develop teaching skills or take part in community activities).*
- *A first version of the TSP should be approved by the (co-) supervisors within three months after starting the PhD trajectory, to be finalized at a more detailed level after 12 months.* [18]*The principles described in the charter apply to PhD candidates who intend to graduate within four years (fulltime; or five years at 0.8 FTE). However, in several TU/e Graduate Programs there are NOP candidates who do not fulfill these criteria, although they are seriously involved in a Graduate Program with the intention to graduate. For these candidates, specific arrangements must be made in accordance with the position of the Graduate School.*

C. PhD (co-)supervisors

(Co-) Supervisors are committed to the TU/e PhD training principles and to facilitate the development of the PhD candidates.

1. The main duties of a (co-)supervisor are:
   a. To supervise the PhD candidates in the realization of their dissertation or technological design; to guide the PhD candidate in their development towards becoming a qualified and independent research professional; and to assist the candidate in finding the best possible position subsequently**.**
   b. To develop a tailor-made program with the PhD candidate.
   c. To monitor the progress of the PhD candidate on a regular basis.
2. (Co-)Supervisors should receive adequate support to fulfill their role as expected**.**
3. (Co-)Supervisors should receive sufficient time to fulfill their role as expected**.**
4. The rights, duties and responsibilities of a (co-) supervisor may be published in more detail in a charter.

[18] *See CAO Nederlandse Universiteiten, artikel 6.8, p.51 (http://www.caouniversiteiten.nl/)*

Remark

- *Adequate support might consist of training and easily accessible monitoring information on the basis of the progress made with respect to the Training and Supervision Plan.*

D. Research Schools

Disciplinary courses are primary offered through Research Schools or similar inter-university networks.

Taking part in a Research School offers additional opportunities for a PhD candidate:

- To follow discipline-specific PhD education and training.
- To build a network of peers at the (inter)national level.

E. Admission and selection

The TU/e admission and selection procedure aims at selecting the best PhD candidates and ensuring the successful completion of the PhD trajectory for all involved.

1. Applicants can only be admitted to a Graduate Program, or be selected for a position, by a selection committee that consists of three members: the intended supervisor and co-supervisor and a third member who is independent of the related research program. The third member could be a colleague, an HR advisor or a member of the MSc graduation committee.
2. Applicants must have strong communication skills, including fluency in written and spoken English.
3. In order to enhance the international visibility of the Graduate Programs, next to individual positions, experiments on batch recruitment may be conducted, provided that at least some funded positions are available. The final selection for a specific position remains the responsibility of the (co-)supervisor(s).

Remarks

- *In batch recruitment, prospective PhD candidates can apply to a program once or twice a year without reference to a specific position at the moment of application. Batch recruitment is especially useful in helping to streamline the admission procedure for PhD scholarships. Graduate Program directors are free to implement this option. In this regard, best practices will be investigated further.*
- *During the selection procedure, the English proficiency level of the candidate will be tested by the selection committee. The results of a language test may also be requested.*
- *The TU/e international admissions office can assist in the admission process at the request of the intended supervisor; for example, in the validation and evaluation of internationally obtained diplomas and degrees.*

- *PhD candidates can only be admitted to a Graduate Program if there is an assurance that the budget and/or the possibilities for education and training, supervision, workplace and other facilities are guaranteed.*

F. Monitoring PhD trajectories

The TU/e Graduate School has monitoring procedures to efficiently reduce (late) drop-out and delay, and pursues graduation on time, based on the PhD registration and monitoring system.

1. All PhD candidates must register at the Graduate School when they start their PhD trajectory.
2. The intended first supervisor is known at the time of registration.
3. A Training and Supervision Plan is formally registered at the Graduate School.
4. There is a formal go/no-go decision after nine months, which is based on an extensive and formal assessment.
5. The Training and Supervision Plan is taken as a reference when making the go/no-go decision.
6. A PhD candidate who is at risk of not fulfilling the requirements to qualify for a PhD degree is informed as soon as possible.
7. The decision will be made by at least three members of staff: the supervisor, co-supervisor and an independent third person, such as, for example, a colleague or an HR officer.
8. PhD candidates are responsible for delivering information about their progress at predetermined times.
9. (Co-) Supervisors will monitor progress informally on a regular basis and formally once a year on the basis of the TU/e PhD monitoring cycle: for example, for a nominal PhD trajectory, at nine months, 30 (Mid-term) and 42 months as a final qualifier before starting the last phase up to the Defense.
10. (Co-) Supervisors and candidates will have easy access to the information used for monitoring: they are the primary users.

Remarks

- *The Training and Supervision Plan is a living document that can be adapted to the needs of the PhD candidate during the PhD trajectory*[19].
- *The third member of the committee should be unbiased with regard to the specific research project and its funding.*
- *The HR cycle and the PhD monitoring cycle have to be brought in line in such a way that a double monitoring cycle will be avoided. The candidate's career preparation should explicitly be addressed.*
- *The monitoring cycle must take into account the requirements of funding organizations (FOM, M2I, DPI, STW, EU, etc.) if applicable.*

[19] *see CAO Nederlandse Universiteiten, artikel 6.8, p.51 (http://www.caouniversiteiten.nl/)*

G. Graduation

The TU/e has sound regulations that guarantee the quality of the conferred degree and facilitates a smooth administrative procedure.

1. The decision on the conferral of the doctoral degree will be taken on the basis of an assessment of the dissertation or technological design and the defense thereof.
2. The procedure that governs the conferral of doctoral degrees, is laid down in the Doctoral Regulations by the Doctorate Board.
3. The Doctorate Committee is composed in such a way that it can guarantee the validity, reliability and transparency of the judgment and is workable with regard to size and other requirements.
4. Facilities should be organized in such a way, that the formal defense may take place within two months after the approval of the dissertation or technological design by the Doctorate Committee.
5. Special requirements for double or joint degrees are defined by the Doctorate Board.
6. PhD candidates may receive the distinction *cum laude*, based on the regulations laid down by the Doctorate Board.

Remark

- *The TU/e does not require a minimum number of accepted or published articles in order to qualify for a PhD degree.*

H. Role of the Graduate School

The TU/e Graduate School (GS) facilitates PhD candidates and (co-)supervisors in achieving high quality PhD trajectories.

1. The GS facilitates the alignment of PhD information.
2. The GS facilitates the registration of PhD candidates.
3. The GS stimulates the organization of community-building activities.
4. Registered PhD candidates will be welcomed at the GS by means of an introductory meeting that is organized by the GS several times a year.
5. The GS is advised by a PhD Council that gives advice to the Dean of the GS on a regular basis and stimulates the organization of community-building activities.
6. At the request of departments and/or (co-) supervisors the GS may assist in the recruitment/ admission process.
7. The GS ensures that sufficient career preparation support is available, both for academic and non-academic careers.
8. The GS offers monitoring information with regard to the implementation of the underlying principles of the PhD training and development.
9. The GS will take measures to offer the support requested by PhD (co-) supervisors.
10. The GS cooperates with all TU/e service departments (such as CEC, DAZ, DPO, IT, O&S, etc.) that are relevant to the implementation of its tasks and responsibilities.

I. Quality assurance

A quality assurance system is in place at all levels.

1. The Graduate School safeguards a quality assurance system for PhD training that, on the basis of adequate monitoring information, continuously ensures that PhD candidates are trained and supervised in the best possible way. This includes ensuring that (co-) supervisors are supported to fulfill their key role in this process.
2. Each Graduate Program is responsible for the quality of its PhD trajectories and for the research and disciplinary courses that PhD candidates follow in their Graduate program.
3. The Doctorate Board is responsible for the quality control of the PhD degree.
4. The Graduate School is responsible for the quality of the transferable skills courses (such as the PROOF courses offered by DPO).
5. PhD candidates have easy access to a contact person who can advise them in case of potential issues on further steps to be taken or on how to resolve issues.
6. Departmental PhD Councils can act as spokespersons for PhD candidates in their Graduate program(s).
7. The TU/e PhD council can act as linking pin with national PhD-candidate organizations.

Remarks

- *An exit interview is foreseen for each PhD candidate with the aim to collect information to improve the PhD programs.*
- *Exit interviews typically can be held by the TU/e HR department, including NOP graduates. Double interviews have to be avoided in the case of external organizations offering exit interviews. Exchange of information is recommended in this respect.*
- *The Dean of the Graduate School has the task to follow developments with regard to future requirements for PhD education and to be involved in relevant national and international networks.*
- *The PhD Councils might be the first low-level access point for PhD candidates to discuss potential issues.*
- *Special attention is required with respect to the quality control of PhD trajectories of candidates who are not on the payroll of the University (see remarks at statements B and E).*

4. Next steps

The presented position statements will be discussed in the Graduate School Consultative Meeting (OGS), the University Consultative Council (BO), the University Council and in the TU/e PhD Council.

For several positions further actions have to be undertaken in order to make it possible to guarantee the implementation of the position statements. The main actions are presented below:

- The formulation of a PhD charter for candidates and (co-)supervisors;
- Possible adaptations of regulations concerning doctoral degrees;
- Adaptation of the monitoring cycle and the HR cycle.
- Adaptation of the set-up of the Training and Supervision Plan;
- The realization and implementation of an adequate registration and monitoring system;
- Review of selection/ admission procedures;
- Set up community building;
- Update PROOF, skills development and career orientation;
- Development of a communication plan: from GS to (potential) PhD candidates, from GS to supervisors, from GS to industry and scholarship providers;
- The formulation of a quality assurance policy.

In order to safeguard that the positions presented in this paper facilitate PhD candidates and supervisors in the best possible way, the involvement of stakeholders will be continued in the implementation phase of this project.

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