Research Self-Assessment 2017-2022

TU/e

EINDHOVEN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF BIOMEDICAL ENGINEERING

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Preface

We are pleased to present you the research self-assessment report of the department of Biomedical Engineering, one of the nine departments of Eindhoven University of Technology. This report has been written as part of the national evaluation process to assess research units in light of their own aims and strategies, following the Strategy Evaluation Protocol (SEP) for 2021-2027 established by Universities of the Netherlands (UNL), the Dutch Research Council (NWO) and the Royal Netherlands Academy of Arts and Sciences (KNAW). It is used to evaluate research quality, societal relevance and viability of research in public institutions in the Netherlands in a six-year cycle.

The report starts with an introduction to the department (Chapter 1) describing its mission, the organization of the department, the scientific profile, positioning at the TU/e, housing and infrastructure and our financial position. Chapter 2 subsequently provides the main strategic aims for the evaluation period (2017-2022), including the response to the previous assessment. The strategy followed to achieve the strategic aims is discussed in Chapter 3, including the major developments during the review period. In the next chapter, Chapter 4, we present and explain the factual evidence and achievements related to the quality of the research and societal relevance in view of the strategic aims. This part is complemented with quantitative indicators and narrative descriptions, as well as several case studies in the appendices. To conclude this research self-assessment report, Chapter 5 reflects on the department's ambitions and strategy for the future. An additional booklet describing the research groups of the department in more detail complements this research self-assessment report.

We would like to thank all those in the department that contributed to this self-evaluation by providing feedback, participating in discussions and writing. We are proud on what we have achieved together with all the people in the department students, scientific and support staff. The achievements and ambitions described in this report are the result of their commitment and dedication to research and education in biomedical engineering.

We hope you will enjoy reading this report and we look forward meeting you in person to discuss our achievements of the past and ambitions for the future.

On behalf of the department of Biomedical Engineering,
Prof.dr. Maarten Merkx (dean), Prof.dr.ir. Keita Ito (vice-dean),
Prof.dr. Josien Pluim (vice-dean), Dr.ir. Wim Koppers (managing director)
July 2023

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1. Introduction

1.1. MISSION

Biomedical engineering represents a multi-disciplinary research field connecting traditional engineering disciplines with the natural and medical sciences. Through our research, we train the next generation of biomedical engineers that combine engineering skills with a strong background in the natural and life sciences to address biomedical challenges. We aim for scientific excellence through an engineering approach, where engineering is defined both as an enabler of scientific and societal progress and as a scientific method to acquire scientific knowledge (learning by making). The combination of engineering and life sciences positions us well to make significant contributions to unraveling the pathophysiology of diseases and to enhancing the diagnostics, intervention and treatment of these diseases. The scientific questions we address are inspired by fundamental challenges in biomedicine and healthcare. We actively pursue the translation of scientific insights into new therapeutic and diagnostic approaches in partnership with hospitals, industry and other healthcare providers, among others, by promoting bio/medtech entrepreneurship among our staff.

1.2. ORGANIZATION OF THE DEPARTMENT

The department is headed by the Department Board, appointed by the Executive Board of the university (Figure 1). The board manages all aspects of the department's business and consists of the dean, two vice-deans and the managing director. The dean leads and represents the

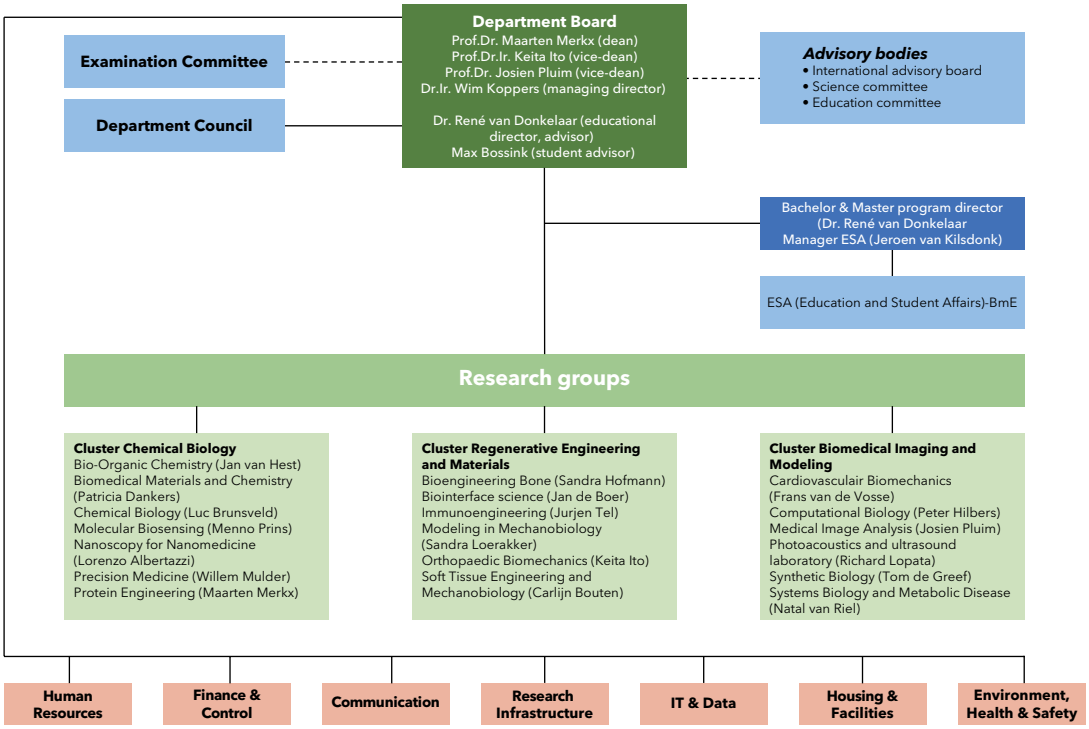

Figure 1. Organizational chart of the Department of Biomedical Engineering. Solid lines represent formal, hierarchical lines, while the dashed lines represent (independent) advisory bodies.

department and is ultimately responsible for all aspects of the department's operations. She/he aligns the departmental policy with that of the university as a whole in close consultation with the Executive Board. The managing director covers all matters concerning personnel and organization, financial administration, services and housing. The managing director heads the Department Office, which provides general support for education, research and valorization, human resources, finance, ICT and data, communication, housing and facilities, research infrastructure, and the environment, health and safety.

Research in the department is organized into 19 research groups headed by group leaders (either full professors or associate professors) reporting directly to the board. Research groups can vary in size from a single academic staff member to groups with a full professor and several assistant and associate professors. The research groups are organized into three clusters that each represent a focus area of the department: Chemical Biology (CB), Regenerative Engineering and Materials (REM) and Biomedical Imaging and Modeling (BIM). Research groups within a cluster coordinate education, take care of joint facilities and coordinate the hiring and guidance of new people (together with the board). The extent of research integration within clusters is variable. In some clusters, the research groups closely align, while in other clusters research activities are more diverse. Nonetheless, some research groups are strongly connected (e.g., Hilbers/Van Riel/de Greef and Van de Vosse/Lopata) within these clusters and strong interactions also exist between clusters, with several researchers operating at the interface of clusters (e.g., de Greef, Grisoni, Dankers, Van Riel, see also figure 2).

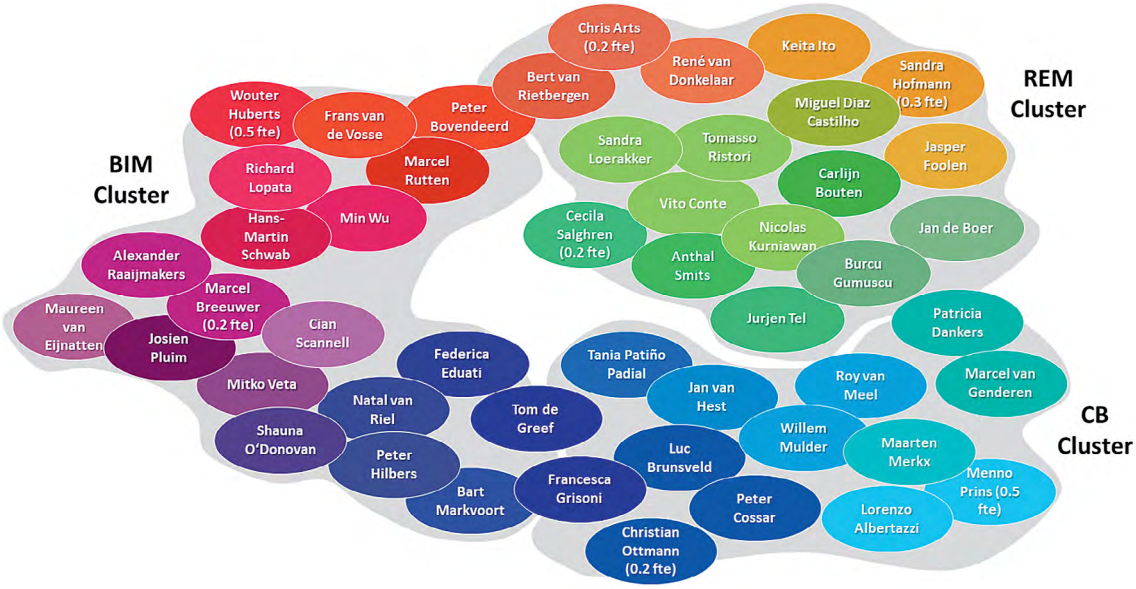

Figure 2. Clusters and academic staff member organization of Biomedical Engineering. The colors represent closely aligned research topics.

Together, the dean and two vice-deans cover the three clusters of the department, ensuring short communication lines and a good representation at the board level. The board meets once every two weeks. The director of education (bachelor's and master's) and a student representative attend the bi-weekly board meeting as advisors. They are not present when the board discusses HR matters, including the recruitment and career development of staff; here, the HR advisor joins the meeting. Every two months, a meeting with all group leaders is organized to discuss topical strategic and operational matters. Twice a year, a two-day meeting with the board and all group leaders is organized to discuss more long-term strategic issues.

Every two months, staff lunch meetings are organized for the entire permanent staff (academic staff, teachers and support staff) to inform and receive feedback on current issues related to research and education. The dean also regularly has 1:1 meetings with the director of education (once per month), group leaders (two to three times a year) and tenure track assistant professors (twice per year) to allow for more informal exchanges of information, advice and feedback. The managing director, HR advisor, financial controller and research support meet with each group leader on a three-monthly basis to discuss operational issues (HR, finances, grant applications).

The department has several advisory bodies:

- Department Council: the participatory body consisting of elected students and employees (five each) that, in addition to providing independent advice, has a legal role in assessing the budget of the department and major organizational and/or educational changes. The council meets every six weeks with representatives of the board.
- Examination Committee: an independent committee consisting of one external and four internal academic staff members and a secretary from the Education Board. The Examination Committee decides on all formal matters related to examinations and educational standards. The director of education and student advisors act as advisors to the committee.
- Program Committee: an internal committee consisting of academic staff members and BSc/MSc students. The committee focuses on the implementation of the education program and examination regulations and discusses matters regarding education, providing solicited and unsolicited advice to the program director and the Department Board.
- Science Committee: consists of six to eight academic staff members to advise the board on strategic matters related to the research-related topics, including the career development of scientific staff, the research strategy and the choice of departmental research awards.
- International Advisory Board: provides independent advice and feedback on the department's research and educational strategies. The board consists of nine members from academia and industry and acts as a peer group representing the different disciplines present in the department (see Table A1 in the appendix for a list of current members).

1.3. CHARACTERISTICS OF THE SCIENCE PROFILE AND EDUCATION

Biomedical engineering, with roots in engineering, life sciences and medical science, is a truly multi-disciplinary research field. While research and education in (bio)medical engineering arose at several Dutch universities at the turn of the century (as part of other engineering departments), TU/e is unique in having a dedicated biomedical engineering department responsible for both research and education. The establishment of a separate department was a deliberate choice. The interdisciplinarity of biomedical engineering requires not simply collaboration between disciplines but true integration, meaning that students have to be trained from the start to work in such an environment. It also requires academic staff with a positive attitude towards other disciplines, joint research programs, and shared laboratories and computer infrastructure.

Following the initiation of an educational program in 1997, the Department of Biomedical Engineering (BmE) was established in 1999 by bringing together professor groups from three different TU/e departments: Janssen and Baaijens (Mechanical Engineering, ME), Hilbers (Mathematics & Computer Science, M&CS) and Meijer (Chemical Engineering & Chemistry, CE&C). The department was further strengthened by the recruitment of several external professors. From the start, a strong culture of collaboration and joint responsibility for both

research and education was promoted by creating an open lab culture and shared budgets and by stimulating joint research programs between the different groups. The BmE department evolved into a research-driven department with a strong scientific profile and reputation. Research is focused on the areas of chemical biology, regenerative medicine and biomaterials, and biomedical imaging and modeling. Compared to other biomedical engineering programs, BmE in Eindhoven has a strong connection with molecular life sciences. Many new research fields at the interface between engineering and medical life sciences are represented, including immunoengineering, systems and synthetic biology, and the application of artificial intelligence (AI) to molecular design, image analysis and medical decision support. In recent years, an increasing number of successful start-ups and incubators have originated from the BmE department, contributing to a growing local biomedical/biotechnology ecosystem.

Since its inception, 50% of students in the biomedical education program have been female, making BmE very successful in attracting female talent to science, technology, engineering and math (STEM) education. With the start of the TU/e-wide Bachelor College in 2012, the department now provides two bachelor's programs: Biomedical Engineering (stronger emphasis on engineering) and Medical Sciences and Technology (stronger emphasis on life sciences). Within several years, the number of first-year students had doubled from 100 to ~200. Because of the strong increase in the number of students, the amount of practical education (both lab work and project work) slowly decreased, particularly in the bachelor's, due to limitations in laboratory infrastructure, manpower and scheduling constraints. The department also provides two research-oriented master's programs. The Biomedical Engineering master's focuses on generic biomedical engineering challenges, whereas the Medical Engineering master's trains students to apply their engineering skills in the clinic to address patient-specific challenges. The latter program runs in collaboration with Maastricht University Medical Center (MUMC+). Additionally, two joint master's tracks have been established together with the University Medical Center Utrecht (UMCU): Regenerative Medicine and Technology (RMT) and Medical

Imaging (MI). BmE also participates in the health track of the interdepartmental master's in Artificial Intelligence & Engineering Systems (AIES), which started in September 2022. A substantial part of the master's education consists of research internships. Typically, 45 or 60 EC is dedicated to an internal final master's project and a 20 EC internship is external, either abroad at another university or at a company. Guidance of master's students is the responsibility of an academic staff member, while daily supervision is typically mandated to PhD students and postdocs in a master-apprentice fashion, implying a direct correlation between the research capacity (labs, funding) and the capacity of the master's programs. Finally, the department is involved in the two-year post-master's Engineering Degree (EngD) program Qualified Medical Engineer (QME), which provides further professional training for biomedical engineers to work in hospitals or to use clinical data.

1.4. POSITIONING AT TU/e AND BEYOND

True to its inception, BmE still has strong connections with the Departments of Mechanical Engineering (ME) and Chemistry and Chemical Engineering (CE&C), as well as with Applied Physics (AP) and Electrical Engineering (EE). These strong connections are supported by the close proximity of BmE research groups in the Gemini (ME), Helix (CE&C), Flux (AP and EE) and Ceres (Institute for Complex Molecular Systems, ICMS) buildings. The group of Jan van Hest was recruited in 2016 as a joint appointment (50/50) between BmE and CE&C. Similarly, the group of Menno Prins (0.5 FTE appointment at BmE) is part of both BmE and AP. Many BmE staff are core members of the Institute for Complex Molecular Systems (ICMS), which has played a pivotal role in stimulating interdisciplinary fundamental research, focusing on advanced materials and engineering health. Several of our current young research leaders had their home base within ICMS (de Greef, Dankers, Loerakker, Albertazzi), an important asset that continues today with a new generation of scientists operating at the interface between different disciplines (Grisoni, Eduati, Van der Meel). Health is one of the three application areas within the Eindhoven Artificial Intelligence Systems Institute (EAISI). While the BmE department is not part of the board of EAISI, several research groups of BmE are strongly involved in EAISI, with EAISI also supporting start-up packages for staff recruited in this area.

At a national level, the department has traditionally strong connections with the Maastricht UMC, which plays an important role in the Medical Engineering master's. Strong ties exist with the BME group at MUMC+, including joint appointments of two associate professors (Van Rietbergen, Arts). More recently, strong connections have been established with the UMC Utrecht (UMCU). A number of shared appointments (Pluim, Ito, Raaijmakers, Dias Castilho) and guest appointments (Veta) were initiated that ensure strong alignment and collaboration in both master's education and research. At the research level, particularly strong collaborations exist in the area of regenerative medicine (RegMed XB, MDR Gravitation program) and through the Centre for Living Technologies, a recent research initiative in the area of synthetic biology supported by the strategic alliance of Utrecht University (UU), UMCU, Wageningen University and TU/e (EWUU). The chemical biology groups traditionally have strong ties with Groningen University and Radboud University (FMS Gravitation program, Big Chemistry Growth Fund), including a part-time appointment of Prof. de Greef at Radboud University. With Radboud University Medical Center (RUMC), the Center for Translational Immunology was established, combining the molecular engineering expertise of the BmE department with the clinical immunology expertise in Nijmegen (Mulder, Netea).

In addition to connections with various university medical centers, traditionally strong collaborations exist with the two top-clinical hospitals in Eindhoven, Catharina Hospital and Maxima Medical Center. Many of these collaborations are also part of e/MTIC, the Eindhoven Medtech Innovation Center that brings together medtech research at TU/e with clinical expertise at the two hospitals and industry, most notably Philips Healthcare. Joint research projects include cardiovascular modeling for clinical decision support (Van der Vosse, Pijls, Lopata, van Sambeek), ultrasound imaging (Lopata, Van Sambeek), perinatal support (Van de Vosse, van Rijn) and orthopedics (Janssen). The department (Brunsveld, Van Riel, Eduati) also closely collaborates with both hospitals within the Expertise Center Clinical Chemistry Eindhoven (ECCCE), including Prof. Scharnhorst as a part-time professor of Clinical Chemistry. In the area of oncology, close connections with the Netherlands Cancer Institute (NKI) in Amsterdam were established with the appointment of Prof. Zwart as a part-time professor at the department.

At the international level, collaborations exist with many international top universities and research institutes, including the EuroTech partner universities (TUM, EPFL, DTU, Technion and Institute Polytechnique Paris). Particularly strong connections also exist with the Wyss Institute (Bouten, Baaijens, Mooney), University of Zürich (Baaijens, Loerakker), UCSF (Brunsveld), several Max Planck institutes (Dankers, Meijer) and the Institute for Bioengineering of Catalonia (IBEC). The latter is a partner institute of ICMS and several of our staff held joint appointments at IBEC before joining our department (Albertazzi, Conte, Patiño-Padial).

1.5. HOUSING AND INFRASTRUCTURE

The department is housed in several buildings on the TU/e campus. Its main locations are in the Gemini and Helix buildings. One of the research groups is housed in the Flux building and some staff have their home in Ceres. Biomedical Engineering has also co-financed and is an important user of the TU/e laboratory for microfabrication (the Microfab/Lab) in Gemini-North.

The various locations strengthen the connections with other departments, but the lack of a home base makes informal interactions within the department more challenging.

One of the strengths of the department is our shared research laboratories, important for attracting and retaining talent and a good way to promote interdisciplinary research. Additionally, the sharing of (expensive) specialized equipment ensures efficient use of the limited departmental budgets while retaining access to a comprehensive collection of state-of-the-art equipment. The use of shared lab facilities also enables a fast start of new research/researchers, although some newly hired staff struggle with the notion of not having 'their own lab'. Although these facilities are successful, maintaining and keeping them state-of-the-art is challenging from both a financial and organizational perspective. The department has therefore hired a departmental research facility manager, responsible for both overall operational management and strategic development. In addition, the research facility manager oversees and coordinates all BmE laboratory-associated building, refurbishment and renovation activities.

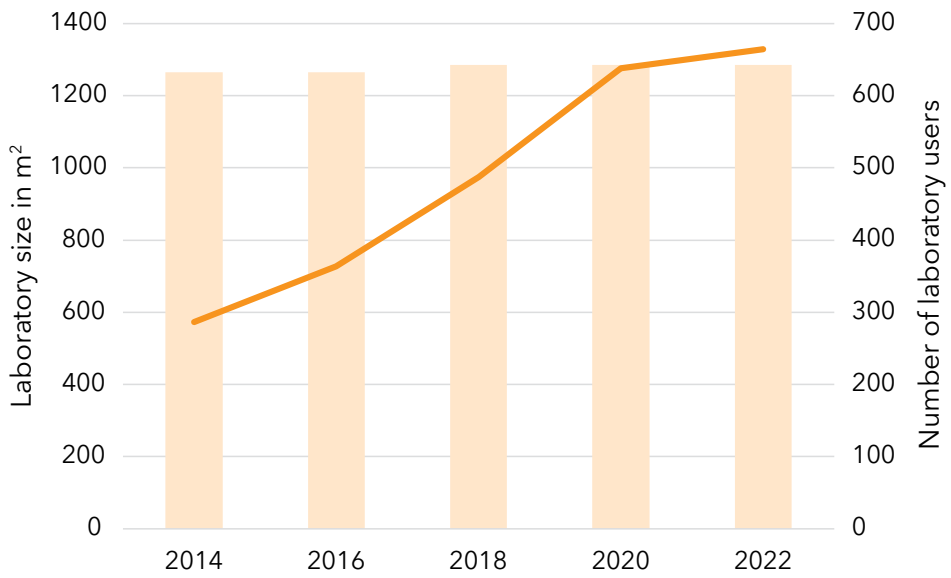

Figure 3. Development of laboratory size (orange bars) in correlation to the number laboratory users (PhD-students, postdocs and MSc-students) over the period 2014 to 2022.

While the number of employees and students has increased substantially over the last six years, the amount of available laboratory and office space has remained the same. As a result, the amount of laboratory m^2 per user decreased from almost 4 m^2/user to 2.2 m^2/user in this period, overloading the laboratory capacity and limiting possibilities for additional collaborations or initiatives. In 2023, 270 m^2 of lab space will become available, increasing this ratio slightly to 2.7 m^2/user.

The two main buildings for BmE, Gemini and Helix, also represent the oldest buildings on the campus by now. Renovation of Gemini-North started in 2022, while renovation for Helix is envisioned in 2030 according to the strategic Campus 2030 plan. A delay has pushed back the realization of the renovated Gemini to 2027. In the planning phase of the Gemini renovation (in 2018), the need for an increased capacity in laboratory space for the department was acknowledged and 1531 m^2 (a 40% increase) was allocated to BmE labs. With the delay in the renovation, the accelerated and partially unforeseen growth of the department and an increased demand for hands-on education, the research facilities are strained anew. During

the renovation of Gemini-South, the department will need to vacate the building at the end of 2024 and will move to temporary housing, currently foreseen at a former Fontys building just outside of the campus terrain. This building first needs to be refurbished quite intensively to allow the housing of our laboratories. However, the much-needed extension of capacity will not be reached before moving back to the renovated Gemini as no increase in laboratory space is foreseen for the temporary housing.

1.6. STAFF AND FINANCIAL RESOURCES

Table 1. Development of the departmental research staff (FTE)

	2017	2018	2019	2020	2021	2022
Assistant professor	15.6	16.1	15.3	17.0	20.8	21.8
Associate professor	8.1	8.9	9.7	8.2	8.2	7.5
Full professor	11.0	11.8	12.9	11.9	11.9	13.1
Total academic staff	34.7	36.8	37.9	37.1	40.9	42.4
Postdocs	30.6	32.6	29.1	39.7	35.9	34.8
PhD candidates	89.0	92.0	117.0	122.8	124.9	133.5
Technical support staff	7.9	7.9	10.6	11.2	11.2	9.6
Total research staff	**162.2**	**169.3**	**194.6**	**210.8**	**212.9**	**220.3**

Table 1 shows the development in the number of academic staff, postdocs, PhD students and technical support staff between 2017 and 2022. Supported by autonomous growth and sector plan funding, the academic staff increased by 20%. Most of this growth was due to the hiring of new tenure track assistant professors, while the increase in full professors resulted from internal promotions of staff members. The number of both postdocs and PhD students increased by 50% over this period, reflecting both an increase in external funding and a growing number of PhD students working in partner institutions (NKI, Philips-e/MTIC, hospitals, ITNs). The number of technical support staff employed by the department remained relatively low.

The direct funding provided by the university is used for the salaries of permanent academic, educational and support staff, for the department's exploitation costs for housing and basic research infrastructure and, to a limited extent, for starting packages. External grants provide for the running costs of research projects, including the salaries of PhDs, postdocs and some technicians, bench fees, consumables and capital investment in equipment. This external funding includes research grants obtained in national scientific competition (e.g., NWO) and contract research, which encompasses a rather broad range of research contracts, including European research funding (ERC, Horizon 2020, etc.), charitable organizations and industry. In the reporting period, both direct funding and external funding grew substantially by 41% and 88% respectively. The department has been particularly successful in obtaining funding based on personal grants (NWO Excellence, ERC programs, ITNs) but is also well-represented by the Gravitation programs (Functional Molecular Systems, Materials-Driven Regeneration, Interactive Polymeric Materials). Other important funding programs in the reporting period included public-private partnerships (PPPs) such as e/MTIC, InSciTe and RegMed XB. Direct funding from industry is relatively underdeveloped.

Table 2. Funding and expenditure of the department in the review period

	2017		2018		2019		2020		2021		2022	
	M€	%	M€	%	M€	%	M€	%	M€	%	M€	%
Direct funding[1]	11.218	69	11.985	62	12.741	60	13.784	65	14.752	62	15.866	63
Research grants[2]	1.121	7	1.362	7	1.687	8	2.015	9	2.212	9	2.377	9
Contract research[3]	3.673	23	5.757	30	6.710	32	5.538	26	6.736	28	6.670	27
Other[4]	0.279	2	0.256	1	-	0	0.024	0	0.170	1	0.153	1
Total funding	**16.291**		**19.360**		**21.138**		**21.361**		**23.870**		**25.066**	
Personnel costs	12.612	76	13.671	70	15.944	75	17.434	79	18.566	77	19.596	78
Material costs	1.547	9	2.727	14	2.675	13	2.454	11	2.561	11	3.582	14
Other costs	2.407	15	3.230	16	2.516	12	2.188	10	3.006	12	1.949	8
Total expenditure	**16.566**		**19.628**		**21.135**		**22.076**		**24.133**		**25.127**	

University funding in the Netherlands consists of:

1 Direct funding from the government (lump sum budget) via the university (including special purpose grants i.e., sector plans, Gravitation programs).

2 Research grants obtained in national scientific competition from e.g., the Dutch Research Council (NWO).

3 Contract research on specific research projects obtained from external organizations, such as industry, government ministries, European organizations and charity organizations (e.g., EU projects, industry grants and grants from public-private partnerships).

4 Other funds that do not fit in the other categories.


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Do not deep freeze
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2. Strategic aims

2.1. MAIN STRATEGIC AIMS FOR THE REVIEW PERIOD (2017-2022)

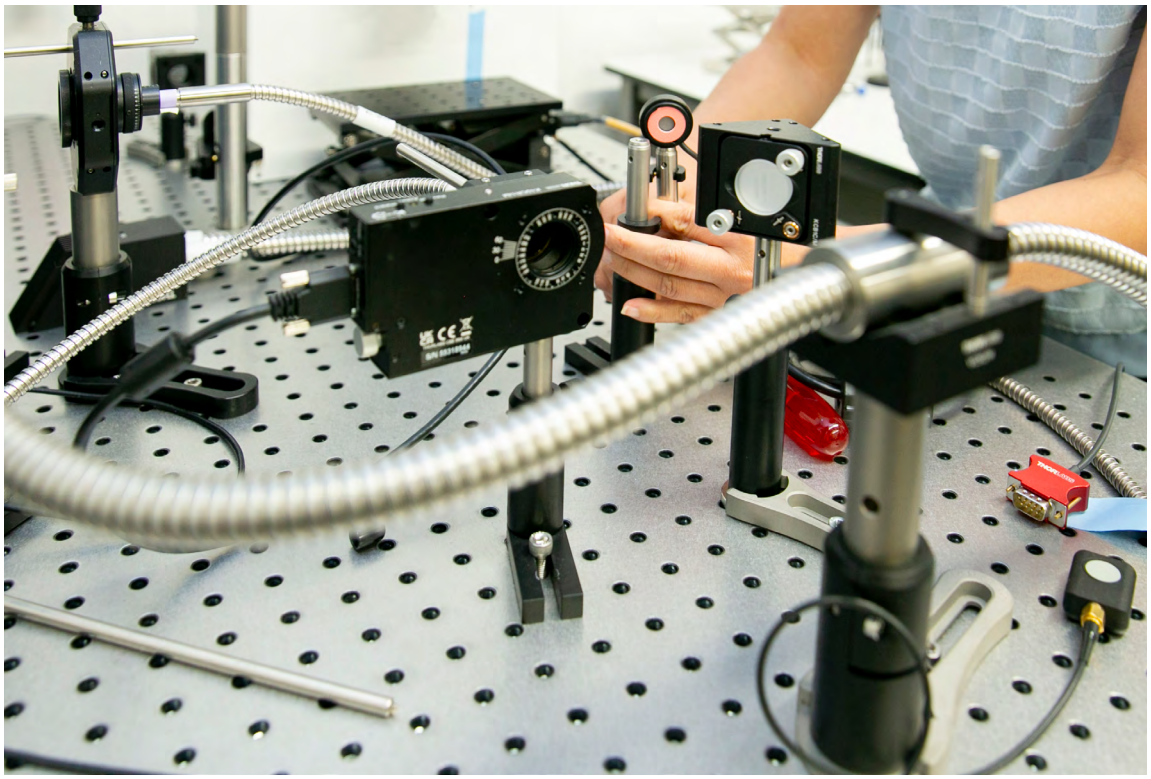
The main strategic aims to achieve our mission are based on three pillars.

Excellent people. It all starts and ends with people. The main mission of the department is to educate people and provide them with the knowledge and skills to contribute to society as knowledgeable, entrepreneurial and responsible biomedical engineers. To do so, we provide a safe and open environment that challenges students and staff to learn, explore and develop their talents. A key principle of university education is the close connection between science and education, where new scientific insights and developments are quickly integrated into education and students learn and are inspired by biomedical challenges. Similarly, we believe that science and scientists also benefit from teaching and the interactions with new generations of curious and ambitious students. Research and education are closely intertwined and form the basis of an academic career. Nonetheless, we also allow differentiation within academic profiles by focusing more on education, research or, in line with the principles of recognition and rewards, differentiated career paths that reward particular achievements in valorization. Leadership qualities are important in all of these areas and are an important aspect of career development.

Excellent science. The incentive to start a Biomedical Engineering program at TU/e was the clear need for innovation in the health sciences and the conviction that this can only be achieved by means of multi and interdisciplinary research and with a scientific staff bearing a

positive attitude towards other disciplines. The department wants to maintain its emphasis on research excellence, with ample opportunities for talented staff to develop into world-leading scientists. We believe that it is important for all academic staff members (ASMs) to develop an independent research profile, which not only recognizes the individual ASM's contribution but is also important to attracting personal funding and becoming an attractive partner in research consortia. To be able to be competitive at the national and international level, both in scientific and translational output and in obtaining large research grants, close collaboration and coherence between research groups in the department is vital. The latter is promoted by the department via shared labs and infrastructure, the organization in clusters and a joint responsibility when attracting new ASMs. Excellence also requires a culture of trust and autonomy in combination with a strong collaborative attitude and joint responsibility.

Societal relevance. The corona pandemic has shown the vulnerability of globalized societies to pandemics and exposed inequalities in their healthcare systems. At the same time, the unprecedented speed by which novel vaccines, therapeutics and diagnostics were developed is a strong reminder of the crucial importance of science and engineering in addressing such global health challenges. Our main contribution to society is therefore the training of biomedical and medical engineers that have the multidisciplinary background needed to address both current and future societal challenges and the development of new knowledge and technology that allow us to address fundamental challenges in biomedicine and healthcare. The combination of engineering and life sciences positions us well to make significant contributions in several exciting and promising research areas, including systems and synthetic biology, the application of AI to molecular design, image analysis and medical decision support, immunoengineering, and regenerative medicine. Research in these areas enables the development of new and more affordable therapeutics, diagnostics and preventive health, with some of the more fundamental research also having the potential to address other global challenges in energy, sustainability and digitization. In addition to its focus on excellent research and education, the department



actively contributes to the creation of an ecosystem of innovative biomedical companies by enabling and promoting the translation of scientific insights into new therapeutic and diagnostic approaches by supporting the development of incubators and by training the talented workforce that is crucial to the success of these companies. Finally, we feel that we have an obligation to society to inform, explain and help navigate people regarding the opportunities and consequences of new developments in healthcare and the biomedical sciences. We stimulate our staff to reach out to the general public on their research and play their role as thought leaders in broader societal discussions regarding e.g., science policy or ethics.

2.2. RESPONSE TO THE RECOMMENDATIONS OF THE PREVIOUS ASSESSMENT

Summary of the previous assessment

In the previous research assessment (2009-2016), the overall research quality of the department was judged as very good to excellent. The department had a strong position in its chosen research fields and was internationally recognized. The committee expected that the results of this excellent research would translate into applications in the field of biomedical technology and advanced healthcare and judged the viability and relevance of BmE as very healthy. Below, we reflect on the recommendations provided by the assessment committee at that time.

Research strategy. Building upon the growth strategy blueprint and the recommendations of the previous research assessment, the department intensified strategic collaborations with several medical departments and bioengineering institutes (see below). As recommended, the department decided to further strengthen existing research areas, such as molecular engineering and regenerative medicine and biomaterials, and to not pursue a new research line in the highly competitive and complex field of neuro-engineering. In the imaging field, the department further strengthened the Photoacoustics and Ultrasound Imaging group. Immunoengineering was further strengthened as a general theme, both in the context of regenerative medicine and tissue engineering and in the fields of bionanotherapeutics, systems biology and single-cell analysis. Artificial intelligence was chosen as an additional important research theme, with new people hired not only in the area of image analysis but also in systems biology, decision support and molecular design.

Organization and infrastructure. Based on the recommendations of the Meijer inter-departmental committee and extensive discussions with the academic staff, the department formulated its vision in the policy document 'Academic staff development at BME: combining individual scientific visibility with collaborative strength' (see Appendix A3). This new policy has provided more clarity on expectations, particularly for our young academic staff, and also resulted in a clearer organization by formalizing the independent organizational status of associate professors that run their own groups. Whereas the three research clusters mainly function internally to coordinate education and research infrastructure investments, research groups are now the main organizational units for research, increasing the visibility of the different research topics and aligning better with the organization of peer institutes. In line with this choice, the background information provided in the separate booklet is organized according to research group. Although the increase in academic staff has provided some relief, the teaching load remains high, among others because it takes some time before new staff can contribute fully to education.

Training and education. Using an increase in direct funding and sector plan means, the department increased its academic staff from 34.7 to 42.4 FTE, which will further grow to 45 FTE in the next years. In addition, an education investment plan (financed by study advance funds) was implemented in 2022 that included the hiring of six dedicated teachers (of which three are structural) and six PhD students with a one-year extension to contribute to education. Concomitant with the increase in staff and as a result of the high success rate in obtaining grants, the number of PhD students has also grown, providing additional capacity, particularly for the supervision of research projects.

Diversity. The department actively supported the university's Irène Curie program to increase the number of women in academia, with 50% of new hires being women. In addition, existing young female staff were supported and promoted to associate and full professor level. Almost all academic staff that were recruited between 2017 and 2022 came from outside of TU/e, with the large majority of new hires coming from abroad or being trained elsewhere. As a result, the percentage of non-Dutch staff increased from 26% to 38%. The department supports diverse career paths, e.g., by allowing some staff to focus on developing their entrepreneurial or educational leadership skills.

Clinical interaction. Collaborations with Eindhoven's top clinical hospitals were further intensified and structurally embedded in the Eindhoven MedTech Innovation Center (e/MTIC) and the Expert Center Clinical Chemistry Eindhoven (ECCCE). In addition, the Center for Translational Immunology was initiated, bringing together our biomedical engineering expertise with the clinical expertise of RUMC around the topic of innate immunity and bionanotherapeutics (Van der Meel, Mulder, Netea). Structural connections were established with the appointment of several new part-time professors, including Prof. Zwart (NKI, drug development), Van Sambeek (cardiology, Catharina Hospital) and Netea (immunology, Radboud UMC). Joint appointments

were also established with the UMCU (Pluim, Ito, Raaijmakers, Dias Castilho) in regenerative medicine and imaging, with MUMC+ in orthopedics (Van Rietbergen, Arts) and with Amsterdam Medical Center (AMC) on systems biology (Van Riel).

Societal relevance. The translation of research was supported by participation in InSciTe and RegMed XB, but also by supporting and allowing research staff to invest time in establishing new spin-off companies. In recent years, this has resulted in a substantial increase in the number of (successful) start-ups and the recent establishment of incubators in the areas of regenerative medicine (SBMC) and bionanotherapeutics (BioTrip). Stronger strategic ties with the province were established and TU/e invested in business development and IP expertise in the medical life sciences (via The Gate).


Logic+

3. Strategy during the review period

3.1. MAJOR DEVELOPMENTS DURING THE REVIEW PERIOD

Sector plans enabled the hiring of additional new staff

Half of the new staff hired in this period were funded by an increase in direct university funding whereas the other half were supported by the sector plans for the beta sciences and engineering. While BmE could not participate as a separate discipline in the sector plans, the department did secure funding for an associate professor in the beta sector plan together with CE&C (Complex Molecular Systems) and four assistant professor positions in the engineering sector plans, of which two were with EE on the application of AI in image analysis and systems biology and two with ME on multifunctional hybrid materials and automated biomaterial discovery. The departmental positions were used to strengthen areas not covered by the sector plans, such as the strengthening of the PULS/e lab (Wu, Schwab), the recruitment of Jan de Boer as a professor of Biointerface Science, the establishment of the Precision Medicine group (Mulder, Van Meel) and the strengthening of the Molecular Biosensing group (Albertazzi) and the Chemical Biology groups (Grisoni, Patiño Padial, Cossar). Many of these new positions further bolstered immunoengineering and artificial intelligence as important general research themes. More details on specific appointments and retirements during the review period are presented in section 4.1.

Cross-disciplinary research as TU/e strategy

Inspired by the successful example of the ICMS, TU/e made the strategic decision to support cross-disciplinary research in a limited number of emerging fields of science and technology. Initially, six cross-disciplinary research themes (CRT) were identified, one of which was engineering health. Based on these CRTs, three new institutes were started: EAISI (AI systems), EIRES (energy) and, most recently, EHCI (photonics and quantum computing). The engineering health CRT became part of ICMS, which subsequently focused its research on engineering health and materials sciences. The BmE department plays a central and leading role in ICMS, which includes joint support services and joint investments in research equipment. 50% of the funding allocated to the institutes was reserved for starting packages for newly hired staff. As a result, all new hires from 2019 onward could be provided with an attractive starting package combining PhD student positions via the institutes (mostly ICMS but also EAISI), departmental support and support by the Irène Curie program.

Changes in the funding landscape

During the review period, the funding landscape underwent some significant changes. While in the past, national funding was mostly distributed via the Dutch Research Council (NWO) in an open competition as personal grants and funding for small research consortia, more and more of this funding is distributed via larger complex consortia including industry, universities of applied science, health funds and societal organizations. Despite the increased competition, the department has so far remained highly successful in obtaining personal and curiosity-based grants, with the European ERC program growing in importance. To be successful in long-term programs such as the Gravitation programs, it is important to maintain this excellence and have

sufficient critical mass in a few focus areas. Furthermore, the department invested proactively in forming national consortia (e.g., RegMed XB), which is critical to being well-positioned to successfully apply to and participate in large initiatives such as Growth Fund investments.

Recognition and rewards

TU/e policy with respect to the (in)dependent position of their academic staff members (ASMs) has changed substantially in recent years. Whereas hierarchical collaboration between full professors, associate professors and assistant professors was the standard in the past, there is a strong push today to increase the visibility and scientific independence of young staff. In addition, the principles of recognition and rewards (R&R) were adopted, providing room and attention for diverse academic career paths. While the ability of academic staff to develop their own independent research profiles is broadly supported within the department, this also raises questions on how this affects the organization of the department, how to accommodate and give room to different talents and career paths and how to value the different contributions of all academic staff members. Based on extensive discussions with the academic staff, the department formulated its vision in the policy document 'Academic staff development at BME: combining individual scientific visibility with collaborative strength' (see Appendix A3). This new policy has provided more clarity on expectations, particularly for our young academic staff, and also resulted in a clearer organization by formalizing the independent organizational status of associate professors that run their own groups. An important aspect is to distinguish between scientific independence and organizational independence. The development of a recognizable scientific profile acknowledges the individual ASM's contribution but is also important to attracting personal funding and becoming an attractive partner in research consortia. However, to be able to be competitive at the national and international level, both in scientific and translational output and in obtaining large research grants, close collaboration between

research groups in the department is also important. Each tenure track assistant professor has a senior staff member (full professor or associate professor group leader) as their supervisor/coach. A new development matrix was recently defined by TU/e to operationalize the principles of R&R, with room for each department to define domain-specific requirements for promotion.

SARS-CoV-2 pandemic (corona)

The SARS-CoV-2 pandemic has had a major impact on both research and education. Following the complete closure of the university buildings for a period of eight weeks (March to May 2020), the department worked hard to enable on-campus experimental research and education within the boundaries of the social distancing rules. The opening times of the laboratories were expanded and work was organized in shifts or three-hour blocks. While these measures resulted in a relatively short complete closure of the buildings, research was still severely affected afterwards due to limited lab access and a lack of social interaction between staff and students as all employees were expected to perform non-experimental work at home. To repair the effect of these delays, extensions have been (and still are) provided to researchers with temporary contracts on a case-by-case basis, which is made possible by additional government funding provided to the university. The corona crisis has also hampered the onboarding and start of newly hired academic staff, particularly because many of them started in this period and came from outside our university. The corona experience re-emphasized the importance of physical and social interactions, not only for well-being but also for research and education quality. The fact that the BmE facilities were already being used efficiently before corona made it an even bigger challenge to allow all researchers access to lab facilities under the constraints of social distancing measures.

4. Evidence and accomplishments

4.1. PEOPLE

In the past six years, the department has expanded its academic staff by 20%. A total of 12 young tenure track assistant professors were hired, half of which were female and supported by the Irène Curie Fellowship program. Many of the senior positions were filled by the successful career development of previously hired staff, which is in line with our policy of enabling promotion based on individual performance (and not the availability of professorship positions). As a result, the overall composition of the academic staff is well-balanced in terms of age, experience and nationality. The percentage of female staff hovers around the critical percentage of 30% but should be further increased in the future to better reflect the fact that 50% of both our undergraduate and PhD student populations are female.

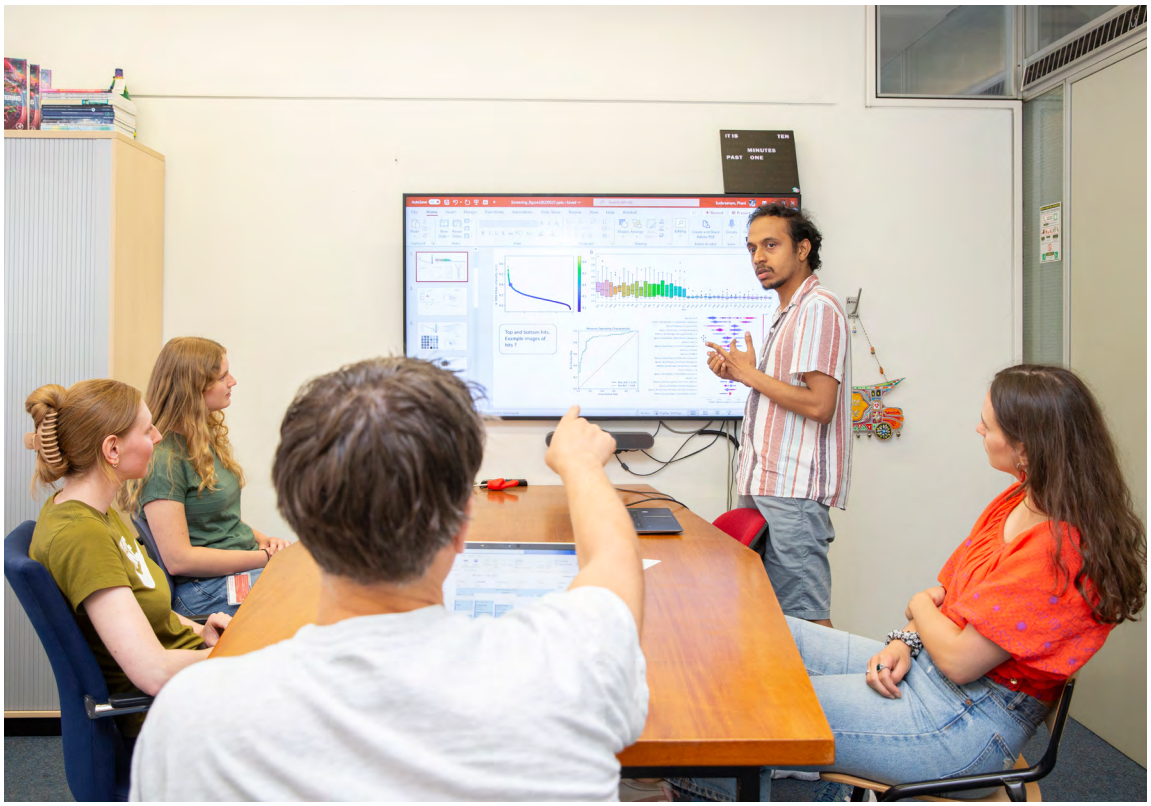
The Chemical Biology cluster was strengthened in 2016 with the recruitment of Prof. van Hest, which ensured the continuation of the close connection between the BmE and CE&C departments after the formal retirement of Prof. Meijer. Supported by an ERC Advanced Grant (2016) and Spinoza Prize (2020), Prof. van Hest built a very strong and productive group, integrated well with the other PIs in the cluster, and took over the leadership of ICMS from Prof. Meijer. The Van Hest group was strengthened by two young assistant professors in this period, Dr. Loai Abdelmohsen (2018, CE&C) and Dr. Patiňo Padial (2022, BmE). Work in the group of Prof. Brunsveld and Dr. Ottmann on small-molecule stabilizers of protein-protein interactions resulted in the successful establishment of Ambagon Therapeutics in 2020. As a result, Dr. Ottmann became the chief scientific officer of Ambagon, reducing his appointment with the department to 0.2 FTE. In 2023, Dr. Peter Cossar has been appointed as an assistant professor to further strengthen the group, also bringing much-needed expertise in organic chemistry and synthesis. In 2018, Prof. Zwart was appointed as a part-time professor of Functional Genomics in Oncology to tighten the connection with the NKI in the development of novel therapeutic strategies in oncology. Dr. Grisoni (2021) was recruited from ETH Zürich to start her own research group on innovative AI approaches for molecule discovery. Her group operates at the intersection of Chemical Biology (Brunsveld) and Computational Biology (de Greef, van Riel, ICMS). The recruitment of Dr. Grisoni is part of wider effort to become a leader in the application of AI and molecular design, which is an important theme within the Growth Fund subsidy on Big Chemistry and will be further supported by positions on AI and biomolecular design (vacancy, BmE) and AI and materials design (CE&C vacancy, ICMS).

Prof. Merkx became the dean of the department in 2019, but also continued his research in biosensor engineering. Research in the area of biosensing and single-molecular biophysics was strengthened by the recruitment of Dr. Albertazzi, who moved his group from IBEC to start as an associate professor of Nanoscopy at the end of 2017. Having successfully obtained Vidi and ERC Starting Grants, Dr. Albertazzi became an independent group leader in 2021, but his group is still working closely with the Molecular Biosensing group of Prof. Prins. Dr. Sergelen started as a tenure track assistant professor in Continuous Biosensing in the Prins group in 2018 but continued her career in 2022 as a research group leader in the BioMed X Institute in Heidelberg.

Research in immunoengineering within the Chemical Biology cluster was strengthened in 2018 by the start of a new research group, Precision Medicine, headed by Prof. Mulder (0.2 FTE) and assistant professor Dr. van der Meel. In 2021, Prof. Mulder ended his appointment at Mount Sinai Medical School (NY) and was given the opportunity to start a second research group focusing on the preclinical validation of bionanotherapeutics at the Radboud University Medical Center (RUMC). Together with Prof. Netea (appointed as a part-time professor in 2022) and his colleagues at the Department of Internal Medicine, the RUMC and BmE groups have formed the Center for Translational Immunology. This center aims to connect the molecular engineering expertise of BmE with the clinical expertise to develop novel immune therapies based on understanding and tuning innate immunity.

In 2017, Prof. Dankers was promoted to full professor and focuses on supramolecular chemistry for the development of biomaterials for regenerative medicine, building a bridge to the Regenerative Engineering groups. Her group was strengthened in 2019 by Dr. van Genderen, who transferred from the group of Prof. Meijer. Research in the area of biomaterials was further strengthened by the recruitment of Prof. de Boer in 2018 as a professor of Biointerface Science. Prof. de Boer's group complements the research in the REM cluster and the Biomedical Materials and Chemistry group of Prof. Dankers by providing expertise in fundamental cell biology and cell-material interactions. This area was further supported by the appointment of Dr. Gumuscu in 2020, who focuses on the development of lab-on-a-chip devices containing hydrogels for high-throughput screening and analysis.

Several other assistant professors started in the REM cluster in this period. Dr. Conte was recruited in 2018 from IBEC, complementing the expertise of the group of Prof. Bouten on synthetic morphogenesis and mechanobiology. Dr. Dias Castilho, who already held a 0.2-FTE appointment as an assistant professor of Biofabrication, transferred his group from the



UMC Utrecht in 2021 to develop instructive materials for regenerative medicine, particularly of musculoskeletal tissues (e.g., bone), combining advanced 3D printing technologies and computational design. Following the retirement of Prof. Oomens in 2020, the computational and modeling expertise in the REM cluster was reinforced by the recruitment of Dr. Ristori (2021). Dr. Ristori has a background in mathematics and develops computational modeling of angiogenesis for tissue engineering applications. Several staff members were also promoted in this period. Supported by ERC Starting Grants and Vidi grants, both Dr. Loerakker and Dr. Hofmann were promoted to associate professor with *ius promovendi* and became independent group leaders. In 2022, Dr. Hofmann decided to move back to Switzerland, but she maintains a part-time appointment with the department. Dr. Tel (ERC StG 2018) was also promoted to associate professor and independent group leader in 2022, with his group focusing on the development of single-cell technology platforms to understand the role of immune cell heterogeneity in immunoregulation and immunotherapy. Dr. Kurniawan and Dr. Smits received ERC Starting Grants and received tenure in this period, as did Dr. Foolen. Associate professor Dr. van Donkelaar became the director of education of the department in 2018.

In anticipation of the retirement of Prof. Hilbers in 2023, the department promoted two staff members in the Computational Biology group to full professor. Following his part-time professorship at the AMC, Natal van Riel was promoted to professor of Systems Biology in 2019. Tom de Greef was promoted to full professor of Synthetic Biology in 2022 in addition to his part-time professorship at Radboud University in Biophysical Chemistry. Following the retirement of Prof. Hilbers, Prof. van Riel and Prof. de Greef will continue to collaborate closely together with several assistant professors of the group. Dr. Federica Eduati started as an assistant professor in 2018, developing systems biology for oncology (tenured in 2022). In 2022, the Systems Biology group was further strengthened by Dr. O'Donovan, who combines AI approaches with physical modeling in immune systems biology.

Two young staff members were hired in the Biomedical Image Analysis group headed by Prof. Pluim. Dr. van Eijnatten (2021) applies deep learning for image reconstruction, segmentation and registration, with applications in image-based treatments such as virtual surgical planning. In 2022, Dr. Scannell was recruited from King's College to work on automated medical image analysis, primarily using deep learning methods. Dr. Scannell filled the vacancy left by Dr. Cheplygina, who was hired as an assistant professor in 2017 but continued her academic career at the International Technical University of Copenhagen in 2021.

Dr. Lopata (ERC, Vidi) was promoted to associate professor in 2017 and given the opportunity to start his own group on photoacoustics and ultrasound imaging (PULS/e). The PULS/e group was further strengthened with two assistant professors. Dr. Wu was brought onboard in 2019 to lead research on photoacoustics and Dr. Schwab started in 2021 with a focus on advanced ultrasound reconstruction and acquisition techniques. The PULS/e lab still collaborates closely with the Cardiovascular Biomechanics group headed by Prof. van de Vosse. In anticipation of the retirement of Prof. van de Vosse in 2024, Dr. Huberts was recruited to become an associate professor (in 2023) and gradually take over the leadership of the Cardiovascular Biomechanics group. The connections with Catherina Hospital were further strengthened by the appointment of clinicians Prof. van Sambeek (2017) and Prof. Dekker (2019, together with EE) as part-time professors.

4.2. RESEARCH QUALITY

As a department, we value excellence and aim to publish in leading high-impact journals and respected society journals, prioritizing quality over quantity. To ensure that our work reaches the user community, translational research is also published in clinical journals. PhD theses are expected to contain four research chapters that are or will be published in leading journals in the field. Table 3 gives an overview of the scientific output of the department during the review period. Compared to the TU/e average, the department scores highly in the Field-Weighted Citation Index (FWCI) and the number of publications in top 1% journals and citation output. A 2021 analysis showed that we also compare well with four peer institutes (IBEC, DTU Health Tech, Imperial College Bioengineering, Cornell School of Biomedical Engineering, see Appendix A1). The percentage of open access publications has steadily increased to >90% and TU/e has recently enabled researchers to allow open access to all publications using the Taverne Amendment to the Dutch Copyright Act. Analysis algorithms, software and databases are made publicly available through public repositories or various GitHub pages, whereas plasmids are made freely available via the non-profit AddGene repository. A departmental data steward was hired to help our staff with various aspects of data management and open science (data storage, FAIR, privacy/ethics). Dr. Lopata is a member of the TU/e Ethical Review Board that reviews all research involving human participants and/or personal data. More detailed information on key publications can be found in the group descriptions (separate booklet).

Table 3. Scientific output in the period 2017-2022

	2017	2018	2019	2020	2021	2022	TU/e
Referred articles	261	275	253	291	277	206	
Book chapters	9	10	9	4	9	3	
PhD theses	15	23	23	22	27	18	
FWCI (Field-Weighted Citation Index)	2.10	1.98	2.38	2.25	2.09	1.67	1.5
Academic-industrial collaboration	8.5%	9.2%	9.5%	7.9%	9.0%	7.6%	9.9%
Publications in top 1% journals	5.5%	7.0%	7.7%	5.8%	5.9%	3.5%	1.7%
Publications in top 10% journals	30.6%	33.1%	30.4%	34.4%	34.5%	25.6%	30%
Outputs in top 1% citations	4.5%	4.7%	7.0%	5.3%	5.1%	2.9%	2.0%
Outputs in top 10% citations	26.9%	31.5%	30.8%	31.8%	26.8%	20.3%	16%
Open access	77.4%	76.0%	75.5%	83.5%	88.2%	90.6%	84%

Despite the increasing level of competition, BmE staff remained highly successful in obtaining personal grants from both the Dutch Research Council (NWO) talent programs (Veni, Vidi, Vici) and the European Union programs (ERC Starting Grants, Consolidator Grants and Advanced Grants). The high number of Vidi and ERC Starting Grants (Table 4) underscores our ability to identify and attract talent, but also to provide a supportive and inspiring academic environment (mentorship by senior staff, support staff, shared facilities). Our academic staff are well-represented at the Eindhoven Young Academy of Engineers (EYAE) and the Young Academy of the Royal Dutch Academy of Science (KNAW). The excellence of senior staff (and their groups) is reflected in the number of Vici and ERC Consolidator/Advanced Grants, the NWO Spinoza Prize and our success within the NWO Excellence program (Gravitation program). The Gravitation program Materials-Driven Regeneration (2017) strengthens the strong bonds with partners in Maastricht, Leiden and the Hubrecht Institute in Utrecht, while the newest Gravitation program Interactive Polymeric Materials (2022) reflects the leading position of TU/e in the field of advanced materials. Another measure of academic excellence is that three staff members – Prof. Bouten (2017), Prof. van Hest (2019) and Prof. Brunsveld (2022) – were chosen as KNAW

members. In particular, our staff involved in the medical and medical application fields have successfully obtained large consortium programs, such as Artificial Womb (Prof. van de Vosse, 2019), Hybrid Heart (Prof. Bouten, Prof. Dankers, 2017), BigPicture (Dr. Veta, 2020) and Ispine (Prof. Ito, 2018), and grants within the Dutch Society for Medical Ultrasound (NVMU), as well as several Innovative Training Network (ITN) programs. Other recognitions of academic potential and leadership can be found in the group descriptions (see separate booklet).

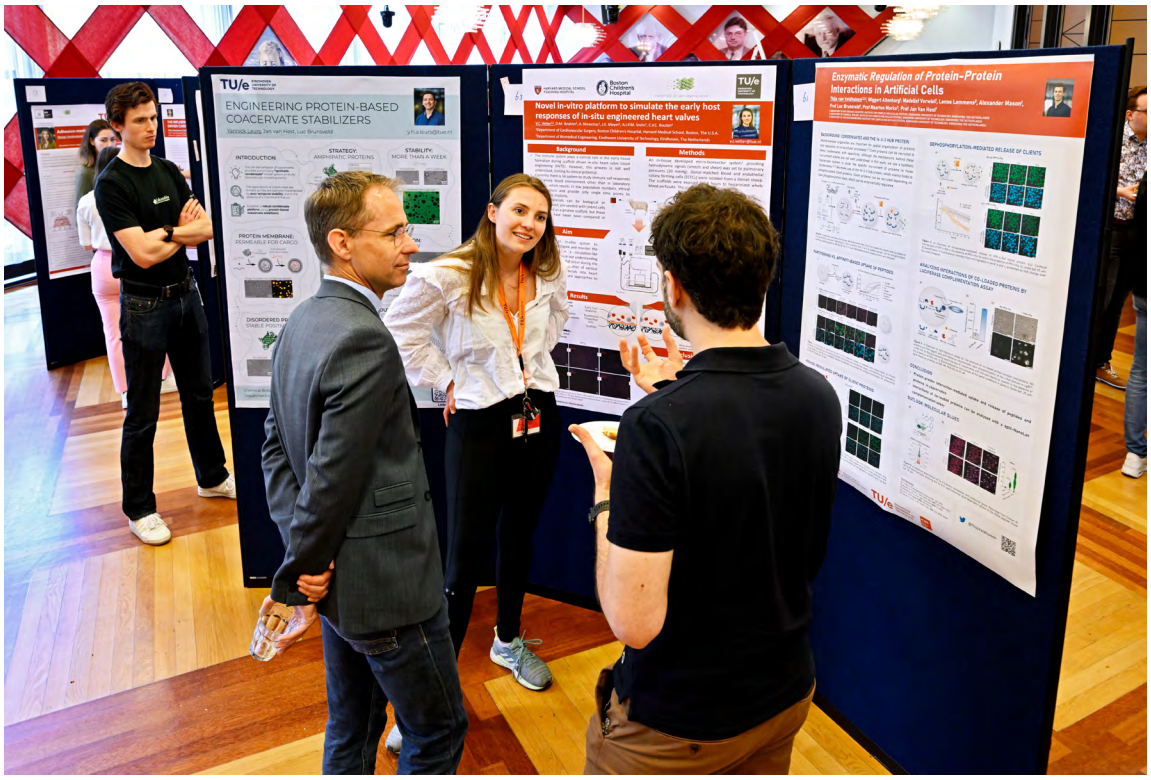
Table 4. Prestigious grants and recognitions

Prizes & Grants	Recipient (year)
Spinoza Prize (NWO)	Jan van Hest (2020)
Gravitation Programs (NWO)	
Functional Molecular Systems (FMS)	Bert Meijer, Jan van Hest (2013-2023)*
Materials-Driven Regeneration (MDR)	Carlijn Bouten, Bert Meijer (2017-2027)*
Interactive Polymeric Materials (IPM)	Jan van Hest, Patricia Dankers (2022-2032)*
Talent Scheme (NWO)	
Veni	Peter Cossar (2021)
Vidi	Patricia Dankers (2017), Tom de Greef (2017), Sandra Hofmann (2018), Richard Lopata (2019), Lorenzo Albertazzi (2019), Sandra Loerakker (2022), Roy van der Meel (2022)
Vici	Willem Mulder (2018), Patricia Dankers (2023)
ERC Grants (European Union)	
ERC Proof of Concept	Maarten Merkx (2017), Patricia Dankers (2017), Tom de Greef (2019), Sandra Hofmann (2020), Lorenzo Albertazzi (2022)
ERC Starting	Lorenzo Albertazzi (2017), Richard Lopata (2017), Jurjen Tel (2018), Sandra Loerakker (2018), Nicholas Kurniawan (2019), Anthal Smits (2022), Francesca Grisoni (2022)
ERC Consolidator	Cecilia Sahlgren (2017), Tom de Greef (2022)
ERC Advanced	Keita Ito (2021), Willem Mulder (2021), Carlijn Bouten (2022), Luc Brunsveld (2023)

* These represent the main applicants; many other staff members are involved in each of these Gravitation programs.

4.3. SOCIETAL RELEVANCE

An important contribution to society is the education of biomedical engineers. Following the introduction of the Bachelor College in 2012, the number of first-year bachelor's students (50% female) increased from 100 to close to 250 in 2017. Between 2017 and 2022, the number varied between 159 and 243 students due to a mandatory *numerus fixus* (2018, 2019), followed by the COVID-19 period of 2020 and 2021. Since the inflow of the bachelor's program consists almost exclusively of Dutch students, maintaining an inflow of 200 students is not trivial because of the decreasing number of high-school graduates, particularly with the required STEM background. The quality of our education was assessed as compliant with international quality (both bachelor's tracks and the BME master's) or above (the ME master's) in the most recent assessment by the Accreditation Organisation of the Netherlands and Flanders (NVAO), which is also reflected in the high appreciation of our students when doing externships at respected research institutes abroad. Our graduates have many job opportunities, with 54% continuing in the private sector (the medical and biotech industry, but also as project managers at e.g., ASML), 38% continuing with a PhD and 5% obtained an Engineering Degree (EngD) for Qualified Medical Engineer



(QME). QME graduates work in hospitals or care facilities on improving and optimizing care processes for clinical problems by applying medical engineering solutions.

The translation of innovative science into new or improved therapies and diagnostics requires close partnerships with clinical partners and the bio/medtech industry. An important way to ensure the translation of research is the appointment of part-time professors, typically active clinicians that translate clinical problems into research questions and implement newly developed technology in clinical practice. We have also strengthened connections with university medical centers and the Dutch Cancer Institute (NKI) via joint appointments or part-time professorships (see above, 4.1). In addition, several of our BmE staff have part-time appointments at university medical centers – Utrecht (UMCU), Maastricht (MUMC), Amsterdam (AMC) and Nijmegen (RadboudUMC) – strengthening interdisciplinary research at the interface between the medical and engineering sciences. Examples include the Center for Translational Immunology, which aims to connect the molecular engineering expertise of BmE with the clinical expertise at RUMC to develop novel immune therapies, and the Expert Center Clinical Chemistry Eindhoven (ECCCE), which was established to promote the translation of innovations in the analytical and data sciences into the clinical chemistry laboratory.

Another route to translate innovative science into medical innovations is via public-private partnerships. The department was involved in the biomedical domain of InScite, which was set up in 2015 by TU/e, DSM, Maastricht University, Maastricht University Medical Center and the Province of Limburg. Through InScite, over €75 M has been invested in projects to develop and apply the production of biobased building blocks and biomedical materials with a focus on technical validation. The Eindhoven Medtech Innovation Center (e/MTIC) was founded in 2018 as a large research collaboration between Catharina Hospital, Máxima Medical Center, Kempenhaeghe Epilepsy and Sleep Center, TU/e and Philips. An important BmE contribution in e/MTIC is the application of ultrasound imaging research as a powerful, cost-effective

imaging option for cardiovascular diagnosis, as well as for treatment planning and guidance. The department is also one of the founders of RegMed XB, Regenerative Medicine Crossing Borders, a public-private partnership dedicated to bringing regenerative medicine solutions to patients and creating a new industrial sector in the participating regions. Some 500 leading scientists at Dutch and Belgian universities and institutes and a range of companies are brought together in RegMed XB.

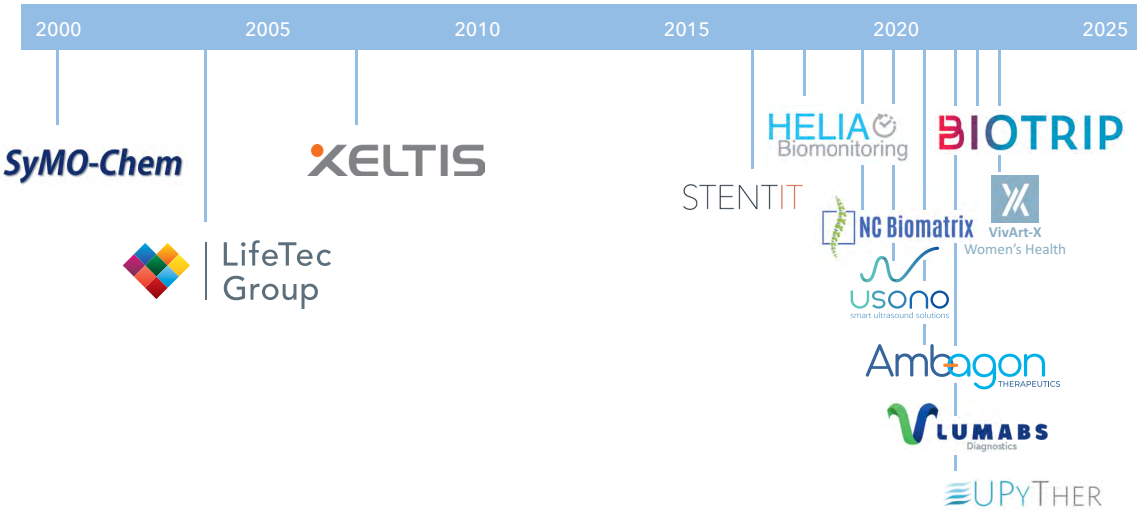


Figure 4. Timeline of BmE start-ups since 2000.

Following earlier examples of successful start-ups such as SyMO-Chem, LifeTec and Xeltis, the number of start-ups has increased sharply in recent years, contributing to a growing local biomedical/biotechnology ecosystem located either on the TU/e campus or at Pivot Park (Oss). Spin-offs started by our department include StentIt, Helia Biomonitoring, USONO, NC Biomatrix, Trained Therapeutics Discovery, Ambagon Therapeutics, LUMABS, UPyTher and VivArt-X. BmE alumni (MSc and PhD) are critical to the success of these companies, some of which have been highly successful in raising funding. The department stimulates and supports start-up companies by allowing dual appointments of our academic staff, enabling them to guide and nurture the critical early phase of these companies, e.g., Ambagon (see also the case study 3), Helia, Trained Therapeutics Discovery and NC Biomatrix.

To provide an ecosystem that nurtures the translation of scientific ideas into new spin-off companies, BmE contributed to the creation of the Smart BioMaterials Consortium (SBMC), which was funded in the first round of the National Growth Fund (see the case study 1). Successful projects funded in round two of the National Growth Fund include PharmaNL and Big Chemistry. Both programs provide funding to invest in advanced research infrastructure (and support) for the high throughput development/screening of bionanotherapeutics, biomaterials and the application of AI. In collaboration with RadboudUMC, the engineering incubator BioTrip was established to further develop patents established within the field of immune therapy by way of an entrepreneurial engine.

Our faculty are well-represented and take leadership roles in national and international academic societies and societal advisory boards and contribute to science as editors of society journals (see the appendix). In our public outreach, we want to inform about both the possibilities and the current state of the technology (without overpromising), but also want to increase interest and enthusiasm in the natural sciences in general, particularly among young people. In this

respect, biomedical research is a great tool to engage young (female) people in the STEM field. This includes various public lectures, such as for Universities of the Netherlands on how our materials are involved in future health applications ('Hoe kan plastic jouw leven redden?', 2017; 'Mighty Materials', 2019; 'Rolt er straks een kloppend hart uit de printer?', 2021) and drug-targeting mechanisms ('Hoe weet een medicijn waar hij heen moet?', 2022), participation in the Eindhoven-based Dutch Design Week (Drivers of Change, 2019, 2022), layman publications, radio contributions and TV interviews. We also actively participate in university or science promotional events such as the TU/e family days, Eindhoven Innovation Café and various TEDx talks.

4.4. TEACHING-RESEARCH NEXUS

Societal developments require different skillsets from future engineers. TU/e realizes that it needs to master new techniques, such as machine learning. At the same time, the professional field stresses the importance of particular soft skills for graduates. Interdisciplinary collaboration, life-long learning and self-awareness are therefore considered new core values for future TU/e engineers. Also, TU/e promotes a shift from traditional frontal lectures to more authentic learning with real-world examples. The university has therefore decided to update its Bachelor College and envisions a prominent place for Challenge-Based Learning (CBL) in its future educational system.

Developments in the clinical and biomedical fields are particularly rapid and these are essential to keeping our healthcare system sustainable with an ageing population. Artificial intelligence, systems thinking and regenerative medicine are examples of approaches that have emerged over the last decades. The increase in student intake, changing demands from society, the expertise of new academic staff, a decline in student appreciation and the vision of the Bachelor College

collectively initiated the development of a new educational program for BmE, ready to start in September 2023. Key aspects in this new program are clearly visible coherent learning lines, a more stimulating, authentic and hands-on learning experience through (practical, disciplinary and interdisciplinary) CBL projects and an approach for self-monitoring the student's personal and professional development.

In the master's phase, each student is coached by an academic staff member in a departmental research cluster of their choice. The students spend two-thirds of the first year following elective courses to deepen and integrate their knowledge. In their internal master's research project of nine to twelve months, PhD students or postdocs guide the master's students to develop into independent researchers. In addition, master's students do a research internship outside of the department and we strongly encourage students to go abroad. In 2022, the department used means from a special corona relief fund to provide 400 euros per student doing an internship abroad.

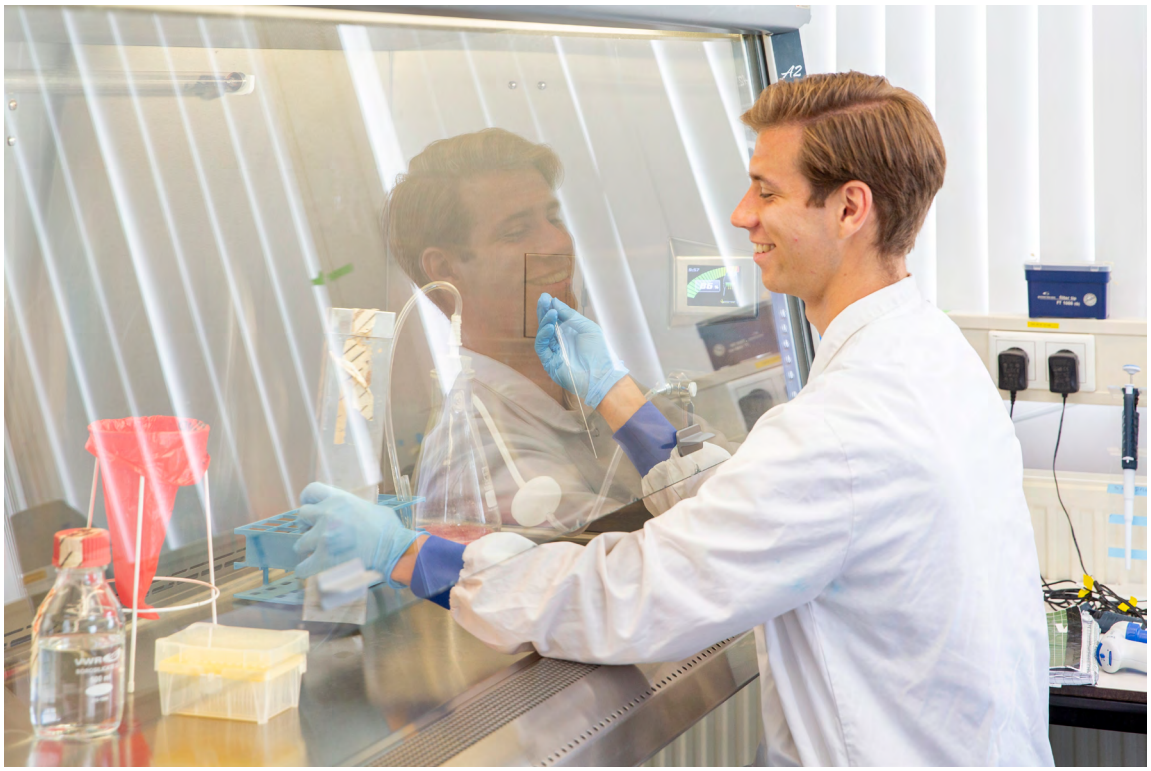
Students are also encouraged to participate in the various student teams at the university. Every year, an iGEM Eindhoven student team participates in the International Genetically Engineered Machine (iGEM) competition to tackle societal challenges with the help of synthetic biology. The Eindhoven team generally does very well and, in 2022, were the overall winners of the undergraduate competition (out of 180!). Inspired by iGEM, Prof. Prins established SensUs, a highly successful international student competition on biosensors for health applications. The SensUs competition is largely organized by students but also involves industry and health partners. Each year, all teams come to Eindhoven to present and test their biosensor designs at the SensUs days.

4.5. PHD POLICY AND TRAINING

The number of PhD students grew significantly from 89 students in 2017 to over 133 in 2022 (see Table 1). Most of the PhD students (~80%) are directly employed by the department and perform their research at TU/e, while another 10-15% are employed at hospitals or in industry. These PhD students are registered as NOP (not-on-payroll) but are treated in an otherwise identical manner regarding training and mentoring. A small number of students (1-5%) are PhD students on external scholarships.

PhD trajectories are demanding and require support in terms of academic and professional development tailored to the needs of the individual PhD student. All PhD candidates are supervised by at least two academic supervisors who act as (co-)supervisors and guide the PhD candidates throughout their project. The supervisor is an academic staff member at a full professor or associate professor level holding *ius promovendi*. The 'Supervising PhD Candidates' course is offered to (co-)supervisors and focuses on communication, supervision styles, expectation management, didactic insights, sharing of best practices and dealing with difficult situations. In addition to the support network available for all TU/e staff, TU/e offers specific support to PhD candidates (PhD counselors and a PhD psychologist).

At the start of the PhD project, a personal training and supervision plan is set up by the candidate and the supervisor, which contains the research plan and the courses that the student intends to follow. These include courses that further develop specific technical knowledge and skills as well as more general soft skills, e.g., PROviding Opportunities For PhD students (PROOF)



courses at the TU/e level and the obligatory 'Scientific Integrity' course. Additionally, workshops, summer school and other training programs are included, as are the agreements on educational tasks. PhD candidates are also encouraged to participate in international conferences to gain international experience. PhD candidates contribute to the department's educational programs as teaching assistants, instructors and tutors. PhD candidates typically spend 5-10% of their workload on guiding students as a tutor or directly in the lab. Most PhD students also have specific lab responsibilities, which can be balanced against the expected teaching load in case this task is substantial. In 2021, the department also introduced the possibility for PhD students to extend their contract by an additional year to take up extra teaching tasks as a PhD-TA (PhD Teaching Assistant, six positions).

The progress of PhD students is carefully monitored and assessed yearly. After one year, a go/no go evaluation is held with the candidate in which progress is assessed at both an academic and a personal level and an evaluation takes place regarding what is needed to bring the candidate to a successful finalization of the project. The progress and well-being of the PhD students are regularly discussed in the three-monthly meetings of the HR advisor and group leader and in the yearly meeting with the PIs. A survey among PhD students in 2022 showed that BmE PhD students are very satisfied (4.2 on a scale of 5; see Appendix A1) with the coaching provided by their supervisors. Recently, the dean and the HR advisor started onboarding meetings with all PhD students at the start of their PhD projects. The dean also performs exit interviews just before the PhD defense.

All administrative aspects related to the onboarding and graduation of PhD students are registered in the administrative system Hora Finita. Hora Finita was introduced in 2020 to improve the efficiency and effectiveness of PhD project administration and allow better monitoring of the PhD trajectory. Towards the end of a PhD, candidates are encouraged to follow a Career Consult Program offered by TU/e's EuFlex employment services.

Table 5. Duration and success rate of the PhD program

Enrolment				Success rate (graduated in ...)					
Starting year	*Enrolment (male/female)*		*Total (M+F)*	*Year 4 or earlier*	*Year 5 or earlier*	*Year 6 or earlier*	*Year 7 or earlier*	*Not yet finished*	*Dis-continued*
2014	11	8	19	4 / 21%	16 / 84%	17 / 89%	-	1 / 5%	1 / 5%
2015	7	6	13	1 / 8%	8 / 62%	12 / 92%	-	1 / 8%	-
2016	17	12	29	0 / 0%	19 / 66%	23 / 79%	-	5 / 17%	1 / 3%
2017	12	14	26	6 / 23%	16 / 62%	21 / 78%	-	1 / 4%	4 / 15%
2018	16	20	36	4 / 11%	17 / 46%*	-	-	16 / 44%	3 / 8%
Total	63	60	123	15 / 12%	-	-	-	26 / 21%	9 / 7%

* Data taken into account until July 2023

Table 5 provides information regarding the duration and success rate of PhD trajectories. On average, 6% of PhD trajectories were discontinued, most of which following the first-year evaluation. Up to the starting year of 2016, success rates were similar to those of previous years (70% within five years, 90% within six years). From 2016 onward, the effect of the corona pandemic is clearly visible in delayed PhD graduations, partially also as a result of the postponement of the graduation ceremony itself. Cohorts starting in 2017 and 2018 had severe restrictions during their PhD research period and approx. 50% of those students received a contract extension (see Table 6). The department continues to assess the need for contract extensions on a case-by-case basis. While the effects of the corona pandemic on PhD durations will remain for the next few years, the department strives to return to a mean PhD duration of 4.5 years in the future.

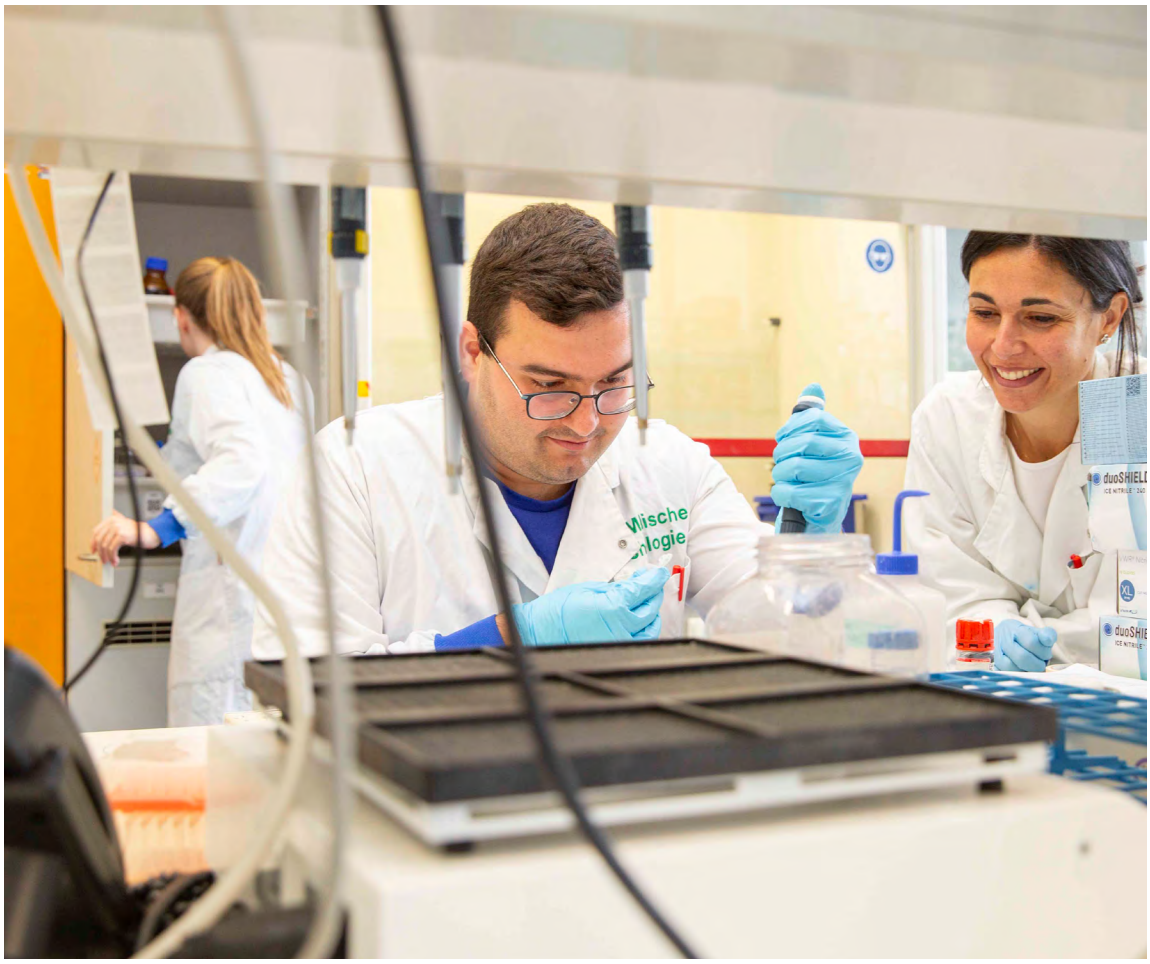


Table 6. COVID-19 extensions

Enrolment				Extension due to COVID-19		
Starting year	*Enrolment (male/female)*		*Total (M+F)*	*Extension*	*Total months*	*Average extension in months*
2014	11	8	19	n/a		
2015	7	6	13	n/a		
2016	17	12	29	14 (48%)	46.5	3.3
2017	12	14	26	16 (62%)	50	3.1
2018	16	20	36	20 (56%)	105	5.3

4.6. HUMAN RESOURCES POLICY

In 2019, TU/e launched its ambitious Irène Curie Fellowship program to increase the number of female academic staff. In addition to providing additional research funding to new female staff, the program required that in the first six months of the recruitment process, only female applicants would be considered. After two years, this program was adapted to be used only for recruiting staff members for positions for which the TU/e targets for female staff members (35% of assistant professors, 30% of associate professors, 25% of full professors) had not yet been reached. In addition, 50% of all sector plan positions were required to be filled by women. Table 7 shows that we have been successful in hiring women, with 50% of newly recruited academic staff between 2017 and 2022 being female. This balanced recruitment has not yet led to a dramatic increase in the percentages of female staff members, partially as a result of internal promotions and two female tenure track professors leaving. The number of female full professors increased to 25%, while the percentages of assistant and associate professors remained more or less constant at 32% and 22% respectively. With the percentage of female staff hovering around the critical percentage of 30%, we still aim to increase this in the future to better reflect the fact that 50% of both our undergraduate and PhD student populations are female. The retirement of (male) academic staff and the promotion of female talent to the levels of associate and full professor will help in further improving the gender balance, provided that we retain an inflow of 50% female staff. As a large majority of newly hired staff came from abroad, the diversity of our staff increased substantially (Table 8: Diversity).

Table 7. Number of newly hired female and male academic staff in the period 2017-2022

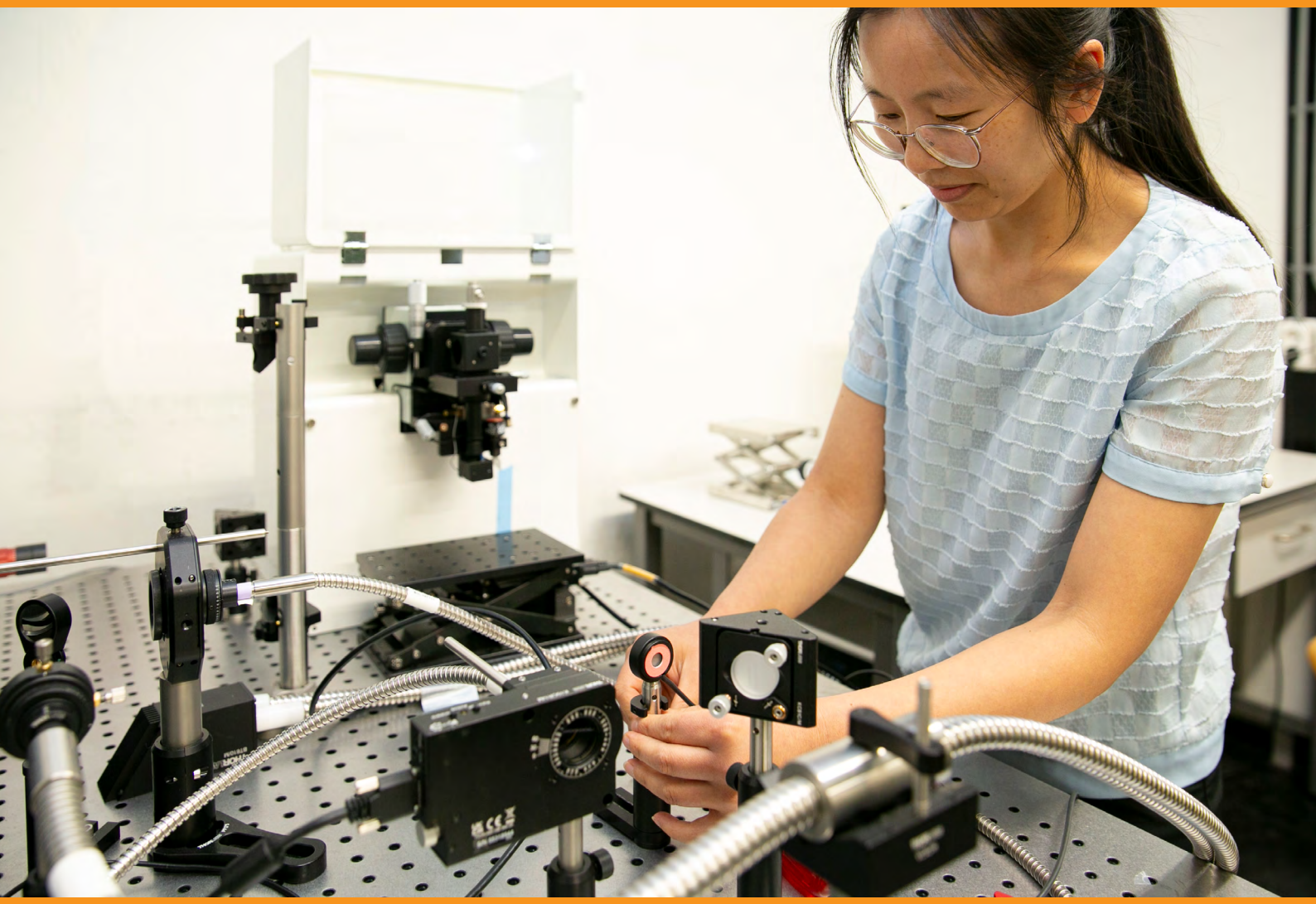
	2017	2018	2019	2020	2021	2022	Total
Number of new female staff	1 (100%)	2 (33%)	1 (50%)	2 (50%)	1 (50%)	2 (66%)	9 (50%)
Number of new male staff	-	4 (66%)	1 (50%)	2 (50%)	1 (50%)	1 (33%)	9 (50%)
Total number of new staff	1	6	2	4	2	3	18

Table 8. Diversity

	2017	2018	2019	2020	2021	2022
Female full prof.	21.4%	21.4%	25.0%	26.7%	26.7%	25.0%
Male full prof.	78.6%	78.6%	75.0%	73.3%	73.3%	75.0%
Total number (FTE)	**11.0**	**11.8**	**12.9**	**11.9**	**11.9**	**13.1**
Female associate prof.	22.2%	20.0%	30.0%	22.2%	22.2%	22.2%
Male associate prof.	77.8%	80.0%	70.0%	77.8%	77.8%	77.8%
Total number (FTE)	**8.1**	**8.9**	**9.7**	**8.2**	**8.2**	**7.5**
Female assistant prof.	31.3%	41.2%	31.3%	33.3%	28.6%	31.8%
Male assistant prof.	68.7%	58.8%	68.7%	66.7%	71.4%	68.2%
Total number (FTE)	**15.6**	**16.1**	**15.3**	**17.0**	**20.8**	**21.8**
International staff	26%	29%	29%	31%	36%	38%
Total number of staff	**34.7**	**36.8**	**37.9**	**37.1**	**40.9**	**42.4**

The department aims for excellent staff with ample development opportunities and early career independence (see also the case study 2). The career development of our staff is carefully monitored and discussed during the annual evaluations with group leaders and in the annual meeting of the Department Board to discuss potential candidates for promotion. Normally, tenure track assistant professors get a midterm evaluation (M-BAC) after two years and a tenure evaluation (P-BAC) after four years. The timing of these can be adapted to the needs of each individual, either to a shorter or longer period (e.g., when the staff member has become a parent). In the reporting period, two tenure track assistant professors decided to pursue their career elsewhere following M-BAC advice. Promotion to the next academic level is merit-based and not dependent on the number of positions in that particular category. As a result, the number of associate and full professors may increase in the future. *Ius promovendi* is now typically granted at the associate professor level upon positive recommendation by the Promotion Assessment Committee (BAC). Promotion Committees require a minimum number of female members and also contain one or more Interdepartmental Committee members (IFCs) that ensure transparency and fair evaluations. The department has appointed three full professors as independent chairs of the committees to ensure consistency of the evaluation process. Members of the Department Board do not take participate in these committees.

In November 2021, BmE volunteered to pilot the new TU/e Employee Experience Survey (EES; see Appendix A1). Both academic staff (including PhD students and postdocs) and support staff experienced a high workload, although this did not translate into a high level of experienced occupational stress. In general, employees reported a high degree of autonomy and the academic staff felt sufficiently challenged. In the allocation of their time, employees reported that they spend more time on organizational aspects and meetings than intended and less time on research. As a department, we strive for an open work climate, which was corroborated by the survey results. Researchers take an interest in each other's work and experience team spirit and companionship, with little competition in their group. Employees were positive about their supervisors with respect to their contribution to a good working atmosphere and the respectful treatment of those they supervise. 6% of BmE employees experienced or observed some form of unacceptable behavior, while similarly low levels were reported for academic misbehavior. Although these numbers are relatively low, the department strives to further decrease these percentages. Based on the results of the EES, the BmE board has asked all three clusters to provide specific points for improvement regarding work pressure and social safety.



5. Strategy for the coming six years

5.1. SWOT

Over the previous six years, the BmE department experienced significant growth in the number of students and staff and amount of funding while maintaining a strong scientific reputation and output in its research fields. Housing and infrastructure did not grow at the same rate, increasing the pressure on staff well-being and productivity and the department's attractiveness (to prospective students and employees). In this period, the connections and collaborations with medical centers were strengthened and the impact of BmE research was enhanced, among others by a substantial increase in the number of start-ups and the establishment of incubators in the areas of regenerative medicine (SBMC) and therapeutics (BioTrip). Many young academic staff were recruited, strengthening both existing research areas with a thematic focus on immunoengineering and the application of AI in all research clusters. In addition, a new, more engaging bachelor's curriculum was designed that involves more research and Challenge-Based Learning, including an investment in additional teacher capacity. While this provides a good starting point for the department, it is important to reflect on future challenges and opportunities, including societal changes. The SWOT analysis provided below is the result of discussions by the Department Board, the Science Committee and the group leaders of the department and is used as a starting point to define and describe the strategy for the coming years.

Strengths

- Overall strong research output that compares well with peers. BmE staff are successful in obtaining personal grants (ERC grants, Veni, Vidi, Vici grants) and other forms of recognition of scientific excellence (KNAW, ZonMw, Spinoza, Gravitation grants).
- Strong infrastructure based on a shared lab culture that stimulates collaborations between research groups. Collegial, collaborative and entrepreneurial culture among people in the department.
- Research and education are highly intertwined.
- The department has a well-balanced staff comprised of young talent and more established, highly successful researchers. In recent years, the department has successfully expanded with young, talented research staff, resulting in new research directions.
- The department is well-represented in regional, national and international research programs and strategic alliances such as ICMS, Eindhoven MedTech Center, National Growth Fund consortia, NWO Gravitation consortia, Perspectief programs and the EWUU Alliance.
- A growing number of successful start-ups and incubators in the areas of regenerative medicine, diagnostics and therapeutics.

Weaknesses

- The department profits less from the Brainport ecosystem than most other departments at TU/e.
- The department is only formally represented in one of the four TU/e institutes (ICMS).
- Many organizations and funding mechanisms are still organized along mono-disciplinary lines (e.g., NWO, ZonMW, sector plans), which can be challenging for multidisciplinary departments such as BmE.
- Insufficient lab and office space limits growth and negatively affects the attractiveness of BmE to prospective new staff and students.
- There is no academic medical center in Eindhoven or a well-established life sciences ecosystem.

Threats

- The temporary relocation of staff and research infrastructure during the reconstruction of the Gemini building could hamper and delay research and hinder interactions among staff and students, both within the department and with other TU/e departments and institutes.
- Uncertainty regarding future permanent housing of the department. The space allocated in the current renovation plans for Gemini is insufficient to accommodate the current size of the department, which may become worse with the future growth of other departments.
- Halting student numbers could negatively affect the direct funding stream, particularly when other departments experience growth.
- Experimental facilities for research and education are relatively expensive compared to some other engineering disciplines.
- Increased pressure for external research funding with a growing number of academic staff at Dutch universities competing for the same or even lower funding, particularly for fundamental and excellence-based research. Continued challenge to access medically-oriented funding (e.g., KWF).

Opportunities

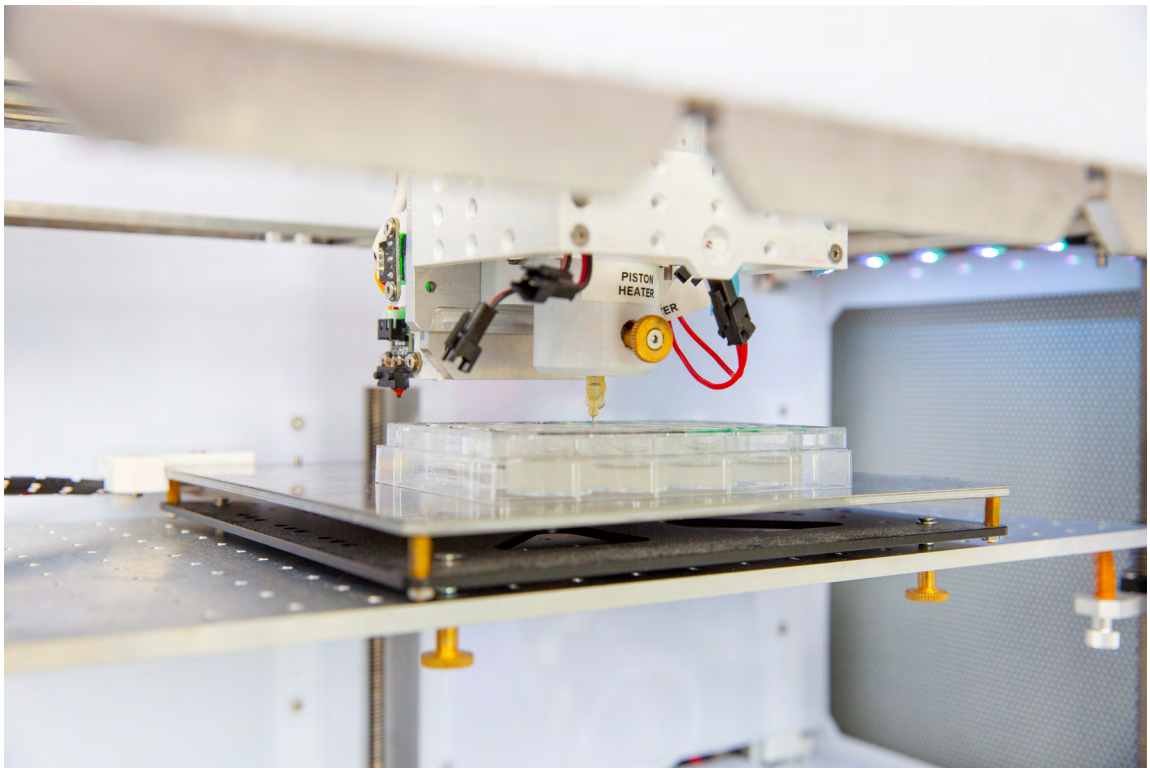
- The multidisciplinary nature and its scientific reputation makes BmE well-positioned to address big scientific and technological challenges at the interface of engineering and life sciences.
- The growing costs of healthcare pose an opportunity for biomedical technology, particularly technology that aids medical professionals in clinical decision-making and care, to handle large patient volumes while reducing costs and improving clinical outcome and quality of life.
- The growing importance of technology will consolidate the role of engineers and clinical physicists in medical centers, increasing the demand for (bio)medical engineers.
- The ambitions of Eindhoven hospitals (Catherina and MMC) and TU/e provide an opportunity for further cross-fertilization of research, education and funding opportunities.
- The strategic alliance with Utrecht and Wageningen provides additional opportunities, not only in research but also in medical education.

5.2. STRATEGY FOR THE COMING YEARS

Societal and technological future developments

Science and education are key enablers of sustainable development and important assets to address current and future societal challenges. Biomedical engineers that combine engineering skills with a strong background in the natural and life sciences are well-equipped to address fundamental challenges in biomedicine and healthcare, but also contribute to other societal challenges. Similarly, some of the fundamental research performed in the department also has an impact beyond the biomedical domain. The most important societal challenge in the healthcare domain is to develop technology that makes and keeps healthcare accessible and affordable for a growing and ageing population. Realizing this will require not only technological innovation but also societal and economic changes, e.g., an increased emphasis on prevention, a decrease in economic inequalities and the development of new business models to involve industry in addressing urgent medical needs.

On the technology side, we expect an increased demand for low-cost diagnostic technologies and remote sensing. Data sciences and the application of artificial intelligence (AI) will further revolutionize healthcare by providing much better and personalized medical decision support. AI will also affect the nature of research and education itself. For example, deep learning is currently revolutionizing structure prediction and the design of proteins and has the potential to do the same for other complex design/engineering problems, including the development of small-molecule drugs, biomaterials and tissues/organs. The successful application of AI in research depends on the availability of well-annotated data or the ability to generate large datasets, which will increase the importance of automated high-throughput experimentation. AI approaches also enable the extraction of high-resolution information from complex, noisy data (e.g., imaging, remote sensors). Applications in healthcare include the remote monitoring of, for example, patients with chronic diseases or patients who leave the hospital after medical



treatment, such as surgery, to recover at home. Guiding/harnessing the immune system to prevent or control diseases (immunoengineering) will increase in importance and result in new therapeutic strategies. Understanding and dealing with the complexity of the immune system also represents very interesting and fundamental scientific challenges, including systems biology, digital twinning and the development of experimental models that capture key aspects of the immune response.

Research strategy

In recent years, we have hired many young academic staff and strengthened the core areas of the department. In the next period, three positions financed by the new engineering sector plan will also be used to hire more senior staff to introduce new research areas that are complementary to the current research groups and become future drivers of research and education. First, we would like to further strengthen the research area of medical engineering and clinical decision support, among others to accommodate the retirement of Prof. Van de Vosse. Hence, an important area that we would like to expand is the field of data sciences and medical decision support. Fundamental challenges in this area are to combine physical models with machine learning approaches and the development of digital twins that integrate molecular data (including genomics), physiological information, and biomechanical and systems biology models. Finally, we are actively scouting for talent in in-vitro human tissue technology for therapeutic discovery and development, as well as young talent in the areas of AI and biomolecular and materials design (together with ICMS, CE&C and the EWUU Alliance).

Alongside the sector plan funding, we expect to have an additional one to two vacancies per year because of retirement and staff pursuing careers elsewhere. These positions will be partially used to support the development and retention of current talent in the department while also keeping an eye on education and disciplinary expertise. We will continue to support newly appointed staff with starting packages, which will be funded by the starting and stimulus grants recently made available by the government (two to three per year). Finally, a small committee will be asked to identify new, promising research directions for the department (including our International Advisory Board, clinical partners, industry, alumni and other societal stakeholders). The aim of this analysis would be to provide guidelines when considering recruitment opportunities and proactively anticipate the retirement of current staff (academic and non-academic). Furthermore, it is critical to invest proactively in forming national consortia (such as Regmed XB) and to set agendas (Dutch Research Agenda, NWA) in order to be well-positioned to participate in such large initiatives, including Growth Fund investments. Navigating this complex landscape is challenging and requires a sustained, long-term strategic research focus.

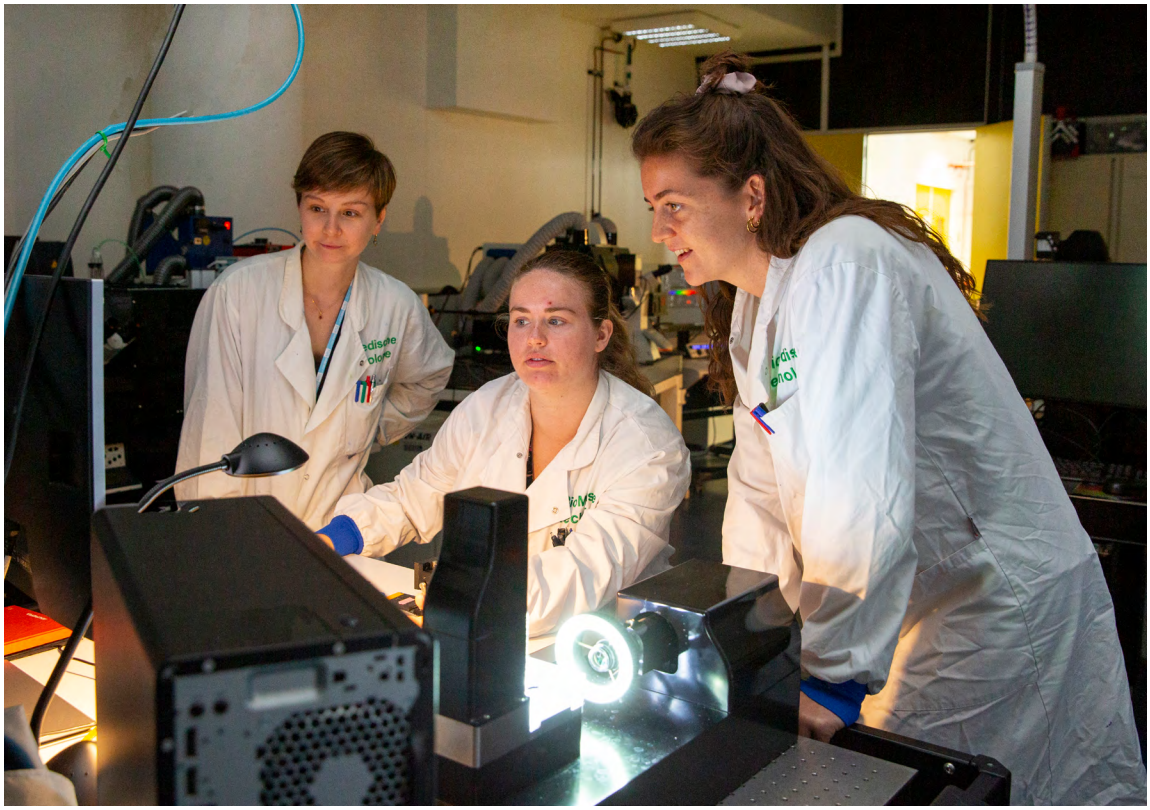
Embedding

The ICMS remains of critical importance to the department as an inspiring home for many of our staff to work on interdisciplinary fundamental research on advanced biomaterials and bioengineering. Together with other departments, we feel responsible for ensuring that ICMS can continue to thrive and we will work closely together with ICMS in joint support services and lab infrastructure. Although the department already plays an important role in the application of AI in health, we have the ambition to further strengthen our role in EAISI and, more generally, to take a leading role in coordinating health research and education in Eindhoven. We would like to further strengthen the connections in this area with the Departments of M&CS, EE and IE&IS. BmE will take the lead in the School of Medical Physics and Engineering with the ambition of

developing this into a TU/e-wide center for post-graduate education (including EngDs) in the health area. The center could be an important part of the to-be-developed Technical Medical Center Eindhoven, which provides another important strategic opportunity to better align our medtech research with that of other departments and strengthen its clinical validation with partners in the Brainport healthcare system. Within the EWUU Alliance, BmE strongly supports the activities in the areas of regenerative medicine (RegMed XB, Gravitation program, master's) and synthetic biology (Centre for Living Technologies). Together with the other three pilot factories, the SBMC will provide an attractive ecosystem for new spin-offs in the area of biomaterials and regenerative medicine. Together with the UMCU, we are also exploring the development of a joint medical bachelor's and master's program that will aim to educate medical doctors with a strong engineering background. The joint PhD program within the EuroTech Alliance will allow us to further strengthen and initiate research collaborations with these peer institutes.

Housing and infrastructure

Our philosophy of shared lab infrastructure has allowed us to use the allotted lab space very efficiently and maintain access to state-of-the-art research infrastructure. However, the growing discrepancy between the number of people and housing has become an important source of work pressure and negatively affects our ability to provide hands-on education and attract new talent. As it is becoming more likely that the future growth of the university cannot be accommodated in the renovated Gemini building, the department has proposed that TU/e invest in a new medtech/life science building. This new building would not only provide a permanent solution (and a home) to the cramped conditions of BME but also a great opportunity to concentrate health-related research and education at TU/e. The building would be a natural and very visible home for the Eindhoven MedTech Center and provide a strong incentive for cross-department and cross-disciplinary collaborations in research, education and valorization.



Whereas adequate housing and labs should be provided by the university, maintaining lab infrastructure and investing in state-of-the art equipment is a responsibility of the department. To accommodate the rising costs of basic lab infrastructure, the department will continue its policy of shared lab facilities. Technical staff that are critical to maintaining these joint lab facilities will be funded by the department, but research technicians will need to be supported by second and third tier funding. Maintaining the department lab infrastructure and support requires that budget for the overhead on grants remain with the department, and the department has made steps to reserve structural funding for investments not only in basic lab infrastructure but also in high-performance computing and data storage facilities. Together with ICMS and other departments, BmE will use recently obtained growth funds (PharmaNL, Big Chemistry) to invest strategically in equipment for the high-throughput screening of molecules and bio/nanomaterials. Additional support for such facilities and advances in 4D material characterization will be sought via the TU/e roadmap for large infrastructure. Where possible, we will also make these facilities and expertise available to outside parties, providing an additional source of income for maintenance.

HR policy: talent attraction, development and retention

The talents, dreams, skills, motivation and resilience of our people together determine the quality and viability of our research and education. Excellence requires a culture of trust and autonomy in combination with a strong collaborative attitude and joint responsibility for people and common infrastructure. These are the characteristics that we look for when recruiting new staff; these are also the key features when attracting new talent. We value and need diversity in the department. Gender is one form of this, but more important is to have people with different backgrounds, perspectives and personal experiences and skills that share a wish to work together, appreciate each other's contribution and share a passion for excellent science and

education. The department is committed to continuing to hire 50% female staff in the future. The department also supports the TU/e development matrix as an important implementation of the principles of recognition and rewards, allowing diversified career paths for our academic staff while retaining the important connection between research and education.

The current tenure track system for assistant professors works well in that it offers a structured way to provide feedback on career development. Even though almost all newly hired staff become tenured, young tenure track assistant professors still experience a lot of pressure, particularly because the criteria for tenure are not absolute (on purpose). As a result, young academic staff sometimes feel forced to keep a lot of balls in the air and focus on short-term goals. The department is therefore in favor of hiring young academic staff on a permanent contract as a UD2 from the start, with the expectation that they develop to UD1 level in four years and to UHD2 level in eight years (on average). This new system requires us to be even more careful in our selection process and maintain or even improve the career track system, including having one or more senior staff members as mentors, ensuring good embedding with existing groups and utilizing the M-BAC as an independent advisory body. A proper career track is important throughout an academic career and the department will discuss the career progress and ambitions of all staff on a yearly basis. Just as important to the success of the department are the well-being, professional expertise and development of our non-academic staff. To be able to attract and retain good people, it is very important to provide a stimulating environment and professional autonomy, as well as to offer the possibility to develop in new roles and responsibilities.

PhD student policy

During the review period, Hora Finita was introduced as a central system to help administer and monitor the PhD trajectory. In addition, the TU/e Graduate School invested in PhD counsellors and provides general PhD courses within the PROOF program. In essence, the PhD is still an individual trajectory, however, where the primary responsibility for proper guidance will remain with the supervisor and co-supervisor (using the four eyes principle). Of course, the department is ultimately responsible for ensuring proper guidance and support for each PhD student. This entails providing adequate HR support, monitoring PhD progress and well-being (first-year evaluation, annual reviews), involving other academic staff for guidance when necessary and providing financing extensions in case of delays beyond the control of the PhD student. To make PhD students aware of the role of the department, onboarding meetings with the dean and HR advisor have been initiated. Here, we discuss the expectations that PhD students have at the start of their PhD and communicate clearly that the success of their PhD is the joint responsibility of the student, their supervisor and the department. While PhD students are represented in the Department Council, we would like to further strengthen and support the PhD community in the department, e.g., via the PhD Student Council. Together with the PhD community, we will work on improving PhD courses and creating an environment in which PhD students can help each other (resilience) and optimally enjoy and appreciate the unique experience of doing a PhD. The department will critically evaluate whether it will continue to accept PhD students with a scholarship from abroad. These students are often paid significantly less than regular PhD students and the conditions of their scholarship can put unhealthy pressure on both the student and the supervisor. Some scholarships also come with increasing risks of knowledge safety.

Excellence in education

At the end of 2021, the BmE department formulated an educational investment plan to provide for more challenge-based and hands-on education to improve the quality and appreciation of its bachelor's education. A new curriculum was developed (starting in 2023) that includes more hands-on and blended education, which also allows us to train the experimental and analytical skills of our students and provide education in smaller groups more systematically. Finally, introducing real-world challenges to this type of education should help our students to appreciate the connection between our education and their future profession. In order to enable more practical and project-based education in our new curriculum without further increasing the workload of our academic staff, the department will use dedicated government funding (study advance funds) to invest in structural positions for highly qualified teachers who will be in the lead for this type of education. Together with our academic staff, they will be responsible for these courses, but will also oversee training and guidance of PhD-TAs and student teaching assistants. These investments should result in higher student appreciation, better educated and more motivated students and a higher retention rate. The education program offered by the BmE department uniquely combines solid training in engineering with a strong background in the natural and life sciences. Sustained attention to outreach and student recruitment will be necessary to keep a sustainable inflow of 200-240 first-years against a demographic trend of declining Dutch student numbers.

Academic culture and outreach

As an academic institution, we have a responsibility to provide an intellectually stimulating environment that allows students and staff to develop and express themselves. To do so, it is important to nurture a culture in which different ideas and opinions are shared and appreciated and collaboration and team science are stimulated. We will more explicitly include these and other aspects of academic culture in our curriculum (including resilience, academic freedom and academic integrity) and regularly discuss these important topics with staff and PhD students.

We also feel that we, as a university, have an important responsibility to society. We stimulate our staff to reach out to the general public on their research and play their role as thought leaders in broader societal discussions regarding e.g., science policy, ethics, etc. Finally, we will invest more in outreach activities for elementary and high school students. Together with our students and student teams, we will seek to strengthen the contacts with STEM teachers at high schools and develop course materials that they can use in their teaching. We will also explore the possibilities to host high-school classes at the university and get them involved in small biomedical research projects. We are convinced that the combination of natural sciences and its application in biomedicine is appealing to high school students and hope that this will stimulate them to choose a STEM profile.

Notes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6. Summary

Ever since the inception in 1999, the department of Biomedical Engineering has established a strong culture of collaboration and joint responsibility for research and education via open labs, shared budgets and joint research programs between BME's 19 research groups. Organized across three clusters – Chemical Biology (CB), Regenerative Engineering and Materials (REM) and Biomedical Imaging and Modeling (BIM) – BME represents a multi-disciplinary research field connecting traditional engineering disciplines with the natural and medical sciences. This positions us to make significant contributions to unraveling the pathophysiology of diseases and to enhancing the diagnostics, intervention and treatment of these diseases. The scientific questions that we address are inspired by fundamental challenges in biomedicine and healthcare. We actively pursue the translation of scientific insights into new therapeutic and diagnostic approaches in collaboration with hospitals, industry and other healthcare providers, resulting in an increasing number of start-ups, in public-private partnerships such as RegMed XB, and incubators in the areas of biomaterials (SBMC) for regenerative medicine and novel immunotherapies (BioTrip).

BME takes a three-pronged approach to its strategic aims:

1. **Excellent people.** The department aims to educate people and provide them with the knowledge and skills of responsible, entrepreneurial biomedical engineers.
2. **Excellent science.** The department wants to maintain its emphasis on research excellence, with ample opportunities for talented staff to develop into world-leading scientists.
3. **Societal relevance.** The combination of engineering and life sciences positions our biomedical engineers well to address both current and future fundamental challenges in biomedicine and healthcare.

In the six years since the previous assessment, BME has seen positive developments in all of these areas, having experienced significant growth in staff and funding while maintaining a strong scientific reputation and output. Many new research fields at the interface between engineering and medical life sciences are represented and an increasing number of successful start-ups and incubators have originated from BME, contributing to a growing biomedical/biotechnology ecosystem. The department has actively supported the university's Irène Curie program to increase the number of women in academia, with 50% of new hires being women. BME staff have also been successful in obtaining personal grants and other forms of recognition and, compared to the TU/e average, the department scores highly in the Field-Weighted Citation Index (FWCI) and the number of publications in top 1% journals and citation output.

Uncertainty lies ahead in the temporary relocation of staff and research infrastructure during the reconstruction of the Gemini building and the unclear future housing of the department, both of which could hamper and delay research and hinder interactions among staff and students. However, BME has proven adept at dealing with similar challenges. For example, the increase in student intake, changing demands from society and a decline in student appreciation have been used to develop a new educational program for BME, starting in September 2023. This offers coherent learning lines, a more stimulating, authentic and hands-on learning experience through practical, disciplinary and interdisciplinary Challenge-Based

Learning projects and an approach for self-monitoring of students' personal and professional development.

Overall, as corroborated by the Employee Experience Survey, BME provides an open work climate in which researchers take an interest in each other's work and experience team spirit and companionship with little competition in their group. Employees are positive about their supervisors regarding their contribution to a good working atmosphere and the respectful treatment of those they supervise. These factors and more will help BME to make the most of upcoming opportunities for biomedical technology, particularly technology that enable medical professionals to keep healthcare accessible and affordable while improving clinical outcome and quality of life.

Notes

Appendices

Appendix A1 – Additional tables and figures

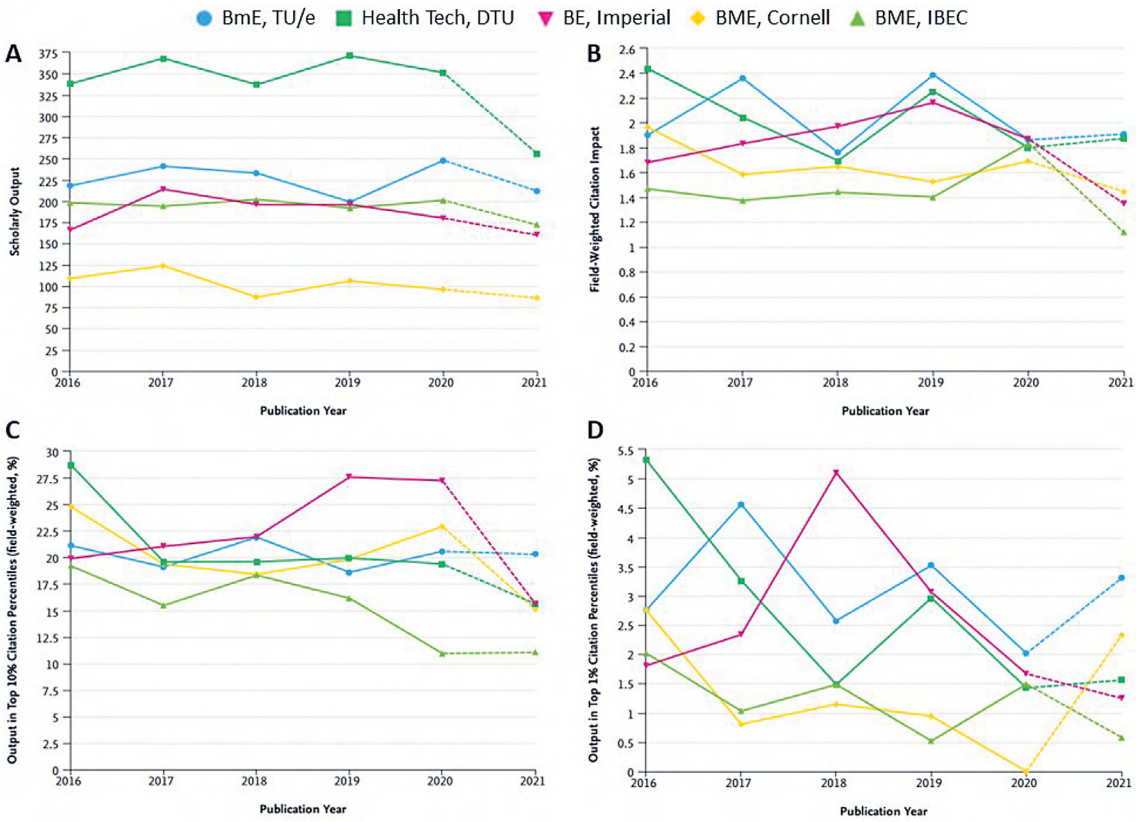


Figure A1. Comparison of Biomedical Engineering, TU/e with four peer institutes in the period 2016-2021. A. Yearly scholarly output, including all types of publications. B. Field Weighted Citation Input. C. Output in top 10% citation percentiles, field-weighted. D. Output in top 1% citation percentiles, field-weighted. BmE, TU/e: Biomedical Engineering at Eindhoven University of Technology; Health Tech, DTU: Department of Health Technology, Technical University of Denmark; BE, Imperial: Biomedical Engineering, Imperial College London, UK; BME, Cornell: Meinig School of Biomedical Engineering, Cornell University, USA; BME, IBEC: Biomedical Engineering at Institute for Bioengineering of Catalonia, Spain.

Table A1. Members of the International Advisory Board

Name	Affiliation
Angelique Balguid	Philips Healthcare, the Netherlands
Tony Cass	Imperial College, United Kingdom
Stan van Boeckel	Pivot Park & European Lead Factory, the Netherlands
Daan Frenkel	Cambridge, United Kingdom
Jane Grand Allen	Rice University, United States of America
Roger Kamm	MIT, United States of America
Ralph Müller	ETH Zürich, Switzerland
Julia Schnabel	TUM, Germany
Carsten Schulz	EMBL, Germany
Frieda van Ginkel	Secretary to the board, TU/e Biomedical Engineering, the Netherlands

Table A2. Valorization of research

	2017	2018	2019	2020	2021	2022
Licenses	1	10	6	12	0	10
Patents	5	3	5	4	5	2
Spin-offs	0	2	1	3	1	2

AP	BmE	BE	CE&C	EE	ID	IE&IS	M&CS	ME	Total
4.1	4.2	3.9	3.5	4.0	3.9	4.1	4.2	4.2	4.0

Figure A2. Satisfaction with the supervision of PhD students. Results from the Employee Experience Survey 2022 for PhD students, comparing the nine departments at TU/e and the average total score. The scale runs from 1 (very dissatisfied) to 5 (very satisfied).

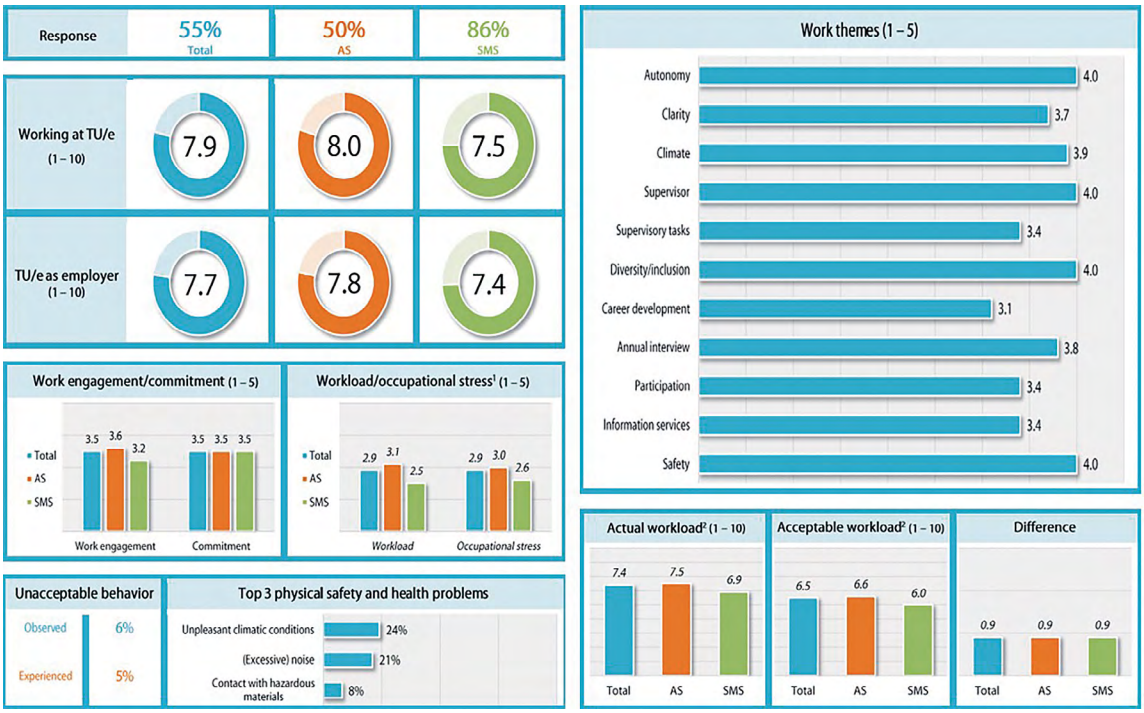


Figure A3. Overview of the BmE Employee Experience Survey 2021 regarding responses, satisfaction, engagement and occupational stress, workload, work themes, unacceptable behavior, and health and safety. Values on workload, work engagement and work themes run from 1 (not) to 5 (very much). AS = academic staff (including PhD students and postdocs), SMS = support and managing staff.

Appendix A2 – Case studies

CASE 1: SMART BIOMATERIALS CONSORTIUM

Context

Whereas in the last decades BmE has become a key player in the development of new concepts in regenerative medicine, bringing these to higher TR levels has been beyond the scope of the department. For example, upscaling, GMP production and the inclusion of regulatory affairs were not readily accessible with the research infrastructure. In 2018, TU/e joined forces with the universities of Utrecht, Maastricht and Leiden to develop a coherent effort to drive solutions forward towards therapies in the area of regenerative medicine. This resulted in a valorization program named RegMed XB that enables the translation of innovative approaches into pre-clinical studies via moonshots in which fundamental research was aligned with the ambitions of health foundations, relevant industries and regional governments. Within the Department of BME, a wealth of insights has been derived in the areas of tissue engineering, biomechanics of soft tissues and the design of biomaterials as supports for cell culturing, scaffolds for tissue formation and biodegradable implants. Many of these activities yielded valuable concepts and, with RegMed XB, translational research and development to bring these solutions closer to the patient could be achieved. Despite the effective public-private efforts to reach the higher TR levels for industrial-driven clinical trials in this emerging market, additional investment was needed and was found in a grant of €56 M provided by the National Growth Fund.[1] Together with the RegMed XB partners, a grant application was compiled that allowed us to build a Pilot

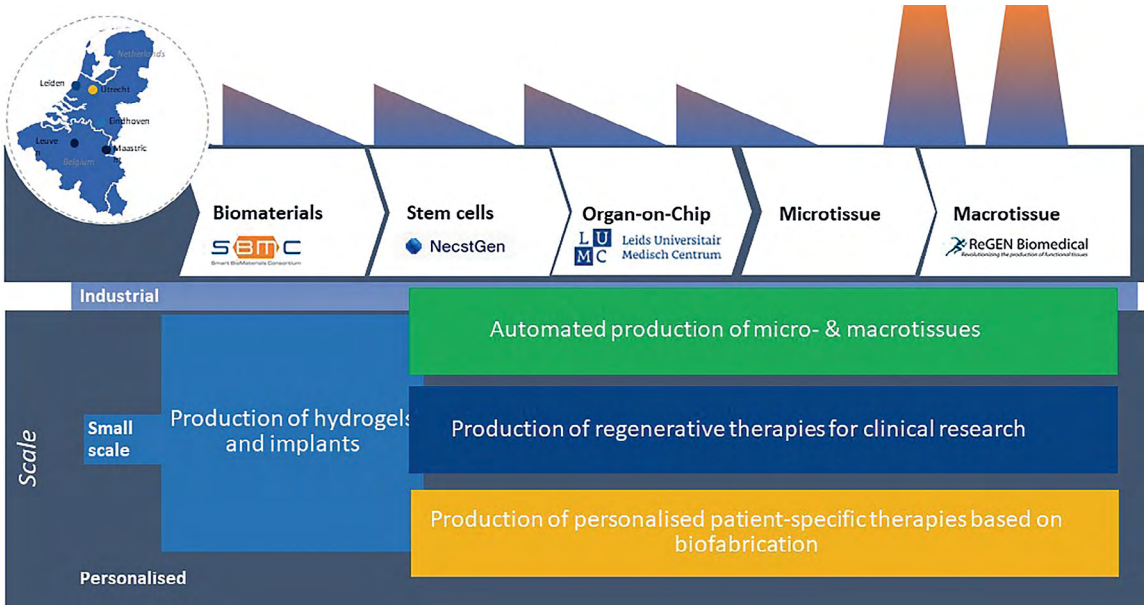


Figure 1. The RegMed XB Pilot Factory. The pilot factory consists of four interconnected hubs (top row) on Biomaterials (SMBC), Stem cells (NecstGen), Organ-on-Chip (to be established at LUMC) and Macrotissue (ReGEN Biomedical) linked to the four academic partners at Eindhoven, Utrecht, Leiden and Maastricht, respectively. Together these hubs give rise to the small scale production of regenerative medical applications, shown in the lower 'scale' block.

[1] With the National Growth Fund, the Dutch government has earmarked €20 billion for the period 2021-2025 for project investments which have the highest potential for structural and durable economic growth, serving society as a whole and enabling the government to continue its investments in healthcare and education.

Factory for regenerative medical applications consisting of four interconnected hubs, linked to the academic partners.

The mission of the RegMed XB Pilot Factory is to accelerate the development of solutions for chronic diseases and to bring affordable regenerative medicine therapies to the patients. The Pilot Factory thus provides an ecosystem of four dedicated pilot lines that enables universities, research institutes, start-ups and industry to (co-)develop, test, upscale and produce new regenerative medicine therapies. The Smart Biomaterials Consortium (SBMC) was linked to one of the strongholds of BME: the design, functional testing and production of biomaterials for medical applications. The SBMC was founded in 2022 on the TU/e campus as an autonomous foundation with an investment of €14.7 M from the National Growth Fund and a €1.4 M in-kind commitment from BME over a period of seven years. In the SBMC development laboratory, the optimization of the design and fabrication of biomaterial products and the evaluation of their safety, efficacy and biological response can be performed. In the SBMC pilot production facility, upscaling and automation challenges for the industrial fabrication of biomaterials and biodegradable implants are tackled in an industrially representative environment, adhering to all applicable regulations and procedures.

Our involvement

For BME, SBMC provides an outlet for the advanced development of our conceptual ideas. As an example, the recent BmE spin-off Vivart-X can be mentioned. In recent years, a biodegradable supramolecular material was developed within BmE that could be employed as a scaffold for transplanted cells applied in breast reconstruction to improve cell vitality. This concept leads to higher (post-)surgical success rates, reduces the emotional strain on cancer patients or woman with a higher risk of developing breast cancer and lowers healthcare costs. Within the contours of TU/e, it would not be feasible to materialize this into an application, but with the SBMC on site it can be propelled forward through the pre-clinical phase. For BME, the SBMC is a meeting place where collaborative projects with industrial partners can be initiated, our potential for material design and functional characteristics can be exploited and we can rely on the expertise and facilities of the other RegMed XB Pilot Factory hubs to valorize our concepts.
The direct involvement of BmE in the SBMC takes place via seats on the Executive Board (Prof. Maarten Merkx), the Program Council (Prof. Patricia Dankers) and the operational team (Dr. Harmen de Jongh) and via the various (former) BmE students/PhDs/postdocs that found positions as staff of the SBMC in different roles. In this way, the SBMC also acts as a breeding ground for young researchers to further develop themselves in the area of biomedical engineering at the intersection of fundamental concepts, industrial applications and societal implementation.

Impact

Although BmE is an internationally recognized stronghold in the development of new concepts in regenerative medicine, bringing these to the higher TR levels has been more difficult to accomplish. To generate societal impact, we have managed, with our investment and direct involvement in the SBMC, to create an ecosystem where we can co-create, together with commercial parties, elaborations of our fundamental research towards clinical applications. In this way, we are also better embedded in the valorization chain and can align our research strategy with a longer-term vision and higher impact.

SBMC has also become a valuable partner for the generation of external funds. Alongside a subsidy by the National Growth Fund, equal volumes of private investments are available within the SBMC that can be used to match grant applications. In this way, the SBMC can act as an autonomous partner in project consortia, allowing the introduction of the significant matching required by most of the funding opportunities. Moreover, the SBMC, as a translational partner in such consortia, warrants the translational potential of more fundamental research activities and contributes to the success rate of our applications. Having direct access to heath technology assessments and regulatory affairs raises the interest of health foundations and insurance companies in being present in user committees in such consortia. Being a key contributor to the ecosystem represented by the SBMC and located on the TU/e campus obviously boosts BmE's collaborative initiatives related to the different expertise that we push forward.
The SBMC was shaped in its present form by BmE, the Brabantse Ontwikkelings Maatschappij and the Province of North-Brabant with support from RegMed XB. This collaborative effort required the alignment of the regional agenda for life science and health with the skill base and potential of TU/e and, in particular, BmE in this area. The regional government adopted the translational development of material-based concepts as a key profile in their Innovation Coalition and recently renewed their commitment to RegMed XB as an illustration of their interest. Also, at an international level, the province uses the activities and expertise of BME to profile itself as the region where functional material design is the home base for innovative medical therapies. From that perspective, BME has become a linking pin between fundamental research, translational developments, regional investments in facilities within Brainport and Pivot Park and the different regional clinics and academic hospitals.

CASE 2: YOUNG TALENT

In the past six years, the Department of Biomedical Engineering has successfully expanded its academic staff from 35 to 42 FTE. A total of 12 young tenure track assistant professors were hired. 50% were female and supported by the Irène Curie Fellowship program, enabling a significant starting package.
Here, three of these young talents, Dr. Francesca Grisoni, Dr. Maureen van Eijnatten and Dr. Min Wu, share their ambitions and their scientific dreams. They also reflect on the role of the department and talk about inspiring students and – not least of all – inspiring themselves.


Dr. Francesca Grisoni

The Irène Curie Fellowship

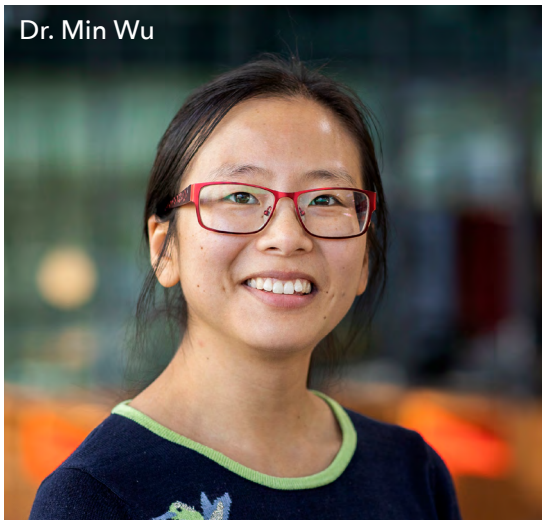
Francesca Grisoni joined the Department of Biomedical Engineering in early 2021. She's leading a team – currently comprised of four PhD students and soon one postdoc and two more PhD students – working on machine learning for drug discovery. Formally part of the Chemical Biology cluster, she and the other researchers share an interest in complex chemical systems and the development of innovative molecular solutions. This offers her team many possibilities for collaboration with other research groups at the interface between machine learning and experiments. Grisoni and her team are currently contributing novel machine learning approaches to the development of bioactive peptides and small-molecule modulators of nuclear receptors and to the prediction of nanoparticle behavior in biological systems, to name but a few fields of research.

It has always been – and still is – her ambition to meaningfully contribute to the discovery of novel therapeutics by developing cutting-edge AI technology. Being the recipient of an Irène Curie Fellowship has been very helpful in this regard, Grisoni says. "The fellowship has allowed me to kickstart my own group, with the security of having enough resources to provide them with good computational resources and travel support. In turn, such security has allowed me to focus my initial efforts on 'aiming high' and writing an ERC Starting Grant, which I was awarded a few months ago. If I had to find safer funding in a shorter timeframe, focusing on the ERC would not have been possible."

The other two assistant professors agree. Maureen van Eijnatten says she chose the tenure track at TU/e over a similar offer at another university because of the generous start-up package; the extra funds allowed her to hire a second PhD student. Min Wu says the fellowship helped her to obtain an advanced photoacoustics research device, a microscopy system which provides for new research possibilities and collaboration opportunities with the Soft Tissue Engineering and Mechanobiology group of the department.

Wu joined the department in 2019. Her research focuses on the development of new photoacoustic imaging systems and analysis methods. She works at the PULS/e group of the department and, like Grisoni, her research strongly connects with that of other research groups.

Min often collaborates with the Orthopaedic Biomechanics group and the Soft Tissue Engineering and Mechanobiology group. She has always appreciated the beauty of the photoacoustics technique, she says, and it is her greatest ambition to bring this technique to medical centers to help clinicians and patients.


Dr. Min Wu

Working at the department

"To start with, I really enjoy the nice working environment of the department," Wu states when reflecting on working at the department. "Colleagues are willing to share and to help each other. And my interdisciplinary research on the development of new photoacoustic imaging systems and processing techniques is highly supported by the shared state-of-the-art facilities in the department. For instance, the Biomechanics Lab is housed with all the facilities for tissue handling, tensile testing, micro-CT testing and biomechanical and medical experimentation to support studies on tissue samples. I also have access to the strong numerical facilities of the department that provide models for different tissue simulations and image reconstruction, a workshop which supports the design and fabrication of various experimental setups and prototypes and a fully equipped tissue engineering laboratory with all of the facilities for histology and advanced microscopy."

Grisoni also strongly approves of the department's laboratory facilities. "The presence of shared wet lab facilities has significantly reduced the barriers to entry, in terms of both cost and time, for the people in my team to experimentally validate the methods we develop," she says, further pointing out that her research benefits greatly from the cutting-edge research that is performed in other groups. "In addition to being a great source of inspiration, the department fosters high-potential collaborations with prominent scientists in their respective fields. I have found many colleagues that are willing to offer feedback, suggestions and insights, which has helped me greatly in starting my own path as a team leader. It is a truly nice and collaborative atmosphere where many colleagues are happy to lift each other up professionally."

The department is also accommodating the young scientists on a personal level. "I received support from the department during my recovery time after my pregnancy, which came with some health complications for both me and my baby," says Maureen van Eijnatten. "I was able to temporarily adapt my work schedule and work more from home and will soon be provided with a standing desk."


Dr. Maureen van Eijnatten

Van Eijnatten has been with the department since 2021. She works at the Medical Image Analysis group (IMAG/e), focusing on CT and CBCT imaging, which is complementary to the

other research lines in the group that mostly focus on MR imaging. Their joint interest in deep learning ensures a fruitful exchange of knowledge that has already led to several joint research projects. Van Eijnatten always dreamt of making a career in research and supervising a small group of researchers. Her interests include deep learning for medical imaging, particularly image reconstruction, segmentation and registration, with applications in image-based treatments such as virtual surgical planning, radiotherapy and medical 3D printing.

"Alongside the personal support and the great support of my research," she says, "the department also offers a personal development plan to generally guide you through your career. Such a plan can be defined with the help of a senior staff member. And there are many courses and teams that can help you to achieve your personal goals, support that includes the BKO teaching qualification (UTQ coaching), funding applications (BmE support team grant), data management (BmE Research IT) et cetera."

The many events organized within the department should also not go unmentioned, says Grisoni. "Events that make people meet and share their research insights, which further promotes the feeling of being in a big and diverse department, which at the same time feels small and familiar."

Research

As mentioned, Grisoni's research focuses on developing novel artificial intelligence methods for drug discovery at the interface between computation and experimental validation in the wet lab. In five to ten years from now, she hopes that her research will have led to unprecedented approaches that augment the capacity of humans to discover novel therapeutics. "It would be great," she notes, "if our algorithms will have contributed to finding promising leads for old and new diseases, for instance, to tackle the antibiotic resistance crisis or rare diseases like cystic fibrosis. Of course, it would be nice if we were the ones to discover such molecules! But at the same time, by providing our algorithms as open-source tools, we want to enable others to build upon our methods for their own drug discovery projects."

Van Eijnatten, reflecting on the future of her specific field of research, states that artificial intelligence has already shown promising results in various medical image acquisition and processing tasks that are crucial to image-guided treatments, such as image reconstruction, semantic segmentation and image registration. "But one of the main challenges faced in the translation of these methods into the clinic, however, is the limited availability of large, annotated datasets with sufficient variability that are required to train state-of-the-art AI models. Until now, few studies have validated proposed deep learning methods on external data, such as images that are acquired from different patient populations in different hospitals using different scanners. As a consequence, current AI methods are often over-adapted to a specific dataset or task, resulting in over-estimation of their applicability in real-life clinical settings. I hope that the AI algorithms that my team and I are working on will have matured so much that they will have been incorporated into routine medical imaging software and devices, thereby reducing the time spent by healthcare professionals on tedious manual tasks."

What does Wu hope her research will have accomplished five to ten years from now? "As it is my goal to bring photoacoustics techniques into the clinics," she says, "I am currently working on photoacoustic imaging of carotid plaques and cartilage damage to improve the diagnosis of strokes and osteoarthritis. I hope that in the near future, the developed techniques can be ready for pre-clinical study to help both clinicians and patients to improve disease management and for the related research community to gain more insight into the pathological process of the disease – plaque rupture or OA – from the perspective of photoacoustics features."

Education

The three assistant professors teach several courses. Grisoni teaches *Advanced programming and biomedical data analysis* aimed at second and third-year bachelor's students. From this year onward, she serves as a responsible teacher and has completely restructured the course to make it more modern and engaging. She is also involved in the Computational Biology DBLs (two to three groups of three to four students each) and guest lectures in the courses Chemical Biology and Machine Learning in Medical Imaging and Biology.

"The greatest joy of teaching," she says, "is witnessing the impact you can have on a student's path in terms of contributing to their personal and intellectual growth and inspiring their curiosity and passion for the subjects you teach. I love it when people proceed in their careers being passionate about the topics I have taught them. For instance, I recently met a postdoc at the University of Copenhagen who chose his path after attending my computer-assisted drug discovery course at ETH. This just made my day. I am also happy when I am a good mentor and I am very proud that two of the PhD students I mentored ended up at Harvard and at the EU's Joint Research Center."

Van Eijnatten, who teaches *Medical Image Analysis*, mostly enjoys teaching in small groups or at an individual level. She says, "I love to see a student grow in a research project and build up their confidence along the way. They need to learn how to build up their own knowledge and skills. If they can gain this ability, they will be able to keep learning for the rest of their careers and lives."

Grisoni agrees. "They have to learn how to navigate the wealth of information available nowadays by locating, evaluating and using information effectively."

Wu teaches *Blood oxygenation measurement with light and sound*. She is also developing a new skills experience project on imaging and measurement, which will start next academic year. When teaching, Wu enjoys seeing students develop during her course, especially in the way they manage to solve problems themselves. "I had one group of students that showed a strong interest in photoacoustics imaging. During their final presentation, I was surprised by their deep understanding of the technique. They studied much beyond my lecture, just by themselves. Another group showed me their photoacoustics processing results based on their own in-vivo measurements. I was impressed by their creativity, how they dealt with the in-vivo data with motion and noise. They combined multiple processing methods and implemented them in a very short period of time."

Inspiration

The department offers a fertile ground for inspiration. Grisoni, Wu and Van Eijnatten say that they get some of their best ideas when talking to colleagues, visiting conferences and reading papers. “But a quiet walk through the forest or on the beach is also helpful,” adds Van Eijnatten. “That usually helps me a lot in ordering my thoughts and making creative and unusual connections between ideas, technologies and applications.” Grisoni says that ideas usually hit her when she expects them the least. “For instance, the idea for my ERC project – and another one for a Vidi I was not granted but I will soon resubmit – consolidated while I was on a plane headed to Italy. Normally, however, I get my best ideas in the shower, while cycling to work or while painting.”

CASE 3: AMBAGON

Entrepreneurship enables the researchers of the Department of Biomedical Engineering to translate scientific insight into new therapeutic approaches to make a difference in healthcare. In the past few years, the number of start-ups that originated in the department has sharply increased.

One of these start-up is Ambagon Therapeutics, a vanguard company developing new oncological drugs and rapidly making a name for itself. Within a short amount of time, the company set up laboratories in the Netherlands and the United States of America and obtained significant Venture Capital funding, which in turn attracted significant attention by (inter)national media outlets. Currently, Ambagon employs over 40 scientists, several of them who started their careers as a student in the labs of Biomedical Engineering - which is also where this case study takes off.

Department origins

The technology developed at Ambagon originates from the chemical biology corner of biomedical engineering, from within the group of Luc Brunsveld and Christian Ottmann, professors of Chemical Biology and Structural Biology at the Department of Biomedical Engineering and two of the company's founders. More specifically, the work of their team focuses on the group of 14-3-3 proteins.

Pivotal to regulation by protein kinases, 14-3-3-proteins recognize, bind and stabilize phosphorylated proteins. As a result, these phosphorylated proteins are stimulated and can exert their function. The research performed on these proteins, encompassing many years, has resulted in a thorough understanding of the binding of 14-3-3-proteins, to the extent that the subsequent effect of binding can be predicted. It is this predictive force that is now key to Ambagon's work.

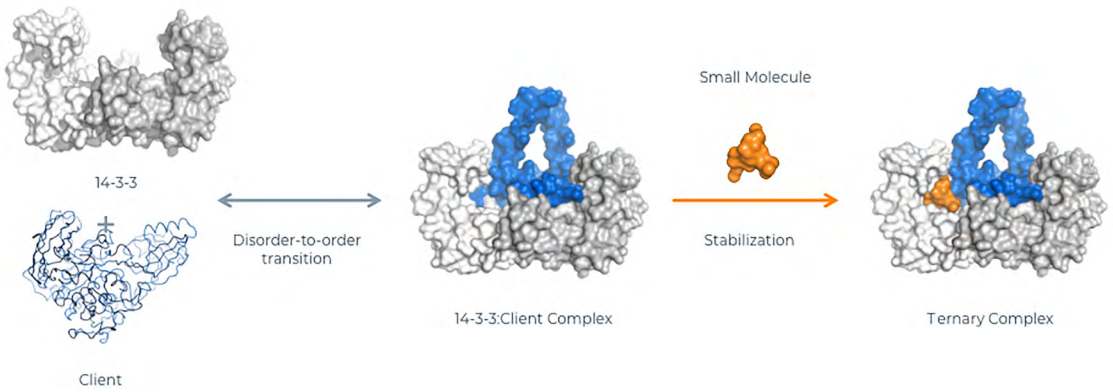


Figure 1. The 14-3-3- stabilization process. The 14-3-3 protein brings order to a disordered client protein when binding. Small molecules subsequently stabilize this complex by acting as a molecular glue.

A closer look

Ambagon develops small molecules that can act as stabilizers for 14-3-3-interactions with specific client proteins, as a sort of molecular glue. Due to the stabilization, the 14-3-3 client proteins can be activated or inhibited. The activation of tumor suppressor proteins would be beneficial in oncological treatment, for example. It is important to note that the type of treatment makes use of a natural regulation mechanism of the body, phosphorylation by kinases and their subsequent 14-3-3 binding. This is not a mere *on/off* function but rather comparable to a tuning of the interaction. In using the molecular glues, the balance of the protein interaction can be shifted towards the desired results.

Ambagon's primary focus is on disease-relevant proteins that have regions of intrinsic disorder that cannot be targeted by conventional small-molecule drugs but are nonetheless relevant to oncological development. Many of those proteins with such intrinsically disordered regions have been identified to interact with the 14-3-3 protein. In binding to a disordered protein, 14-3-3 induces order, conferring druggability.

Starting a company

The journey from fundamental chemical research to the establishment of a full-blown company working from two continents is no mean feat. Even though the idea of a start-up was around for many years, it took time for the ambition to truly blossom. The turning point came in 2018 when Christian Ottmann went for a sabbatical to the lab of Professor Michelle Arkin at the University of California. Arkin joined in Ottmann and Brunsveld's plans and, in 2020, the three of them founded Ambagon, a Dutch-American company with labs in Eindhoven and San Francisco. Since then, Ottmann has combined his position as an associate professor (0.2 FTE) with that of the role of Chief Technology Officer at Ambagon. Brunsveld remains a full professor at the Department of Biomedical Engineering and serves as a scientific advisor to the company.

"Starting a company is, in itself, a great learning experience," Brunsveld was recently quoted in *Innovation Origins*. "We have learned an awful lot of new things, from attracting investors to building a great company team."

Funding

Shortly after founding the company, the team presented itself to investors to secure funding. "That was our coming out," stated Brunsveld in another media outlet, *Het Financieele Dagblad*. "We competed in four venture challenges and won them all. Apparently, our ideas resonated." The wins helped in securing 18 million dollar seed funding from an international group of venture capital companies. "Since our seed investment, the team has developed an impressive proprietary dataset and systemic understanding of 14-3-3 interactions. Ambagon truly has the potential to change the narrative for disordered targets," one of the company's investors was quoted on *pipelinereview.com*, an online biologics news portal.

The seed funding also formed the basis for a Series A financing of 85 million dollar in early 2022. All investors, among them the venture arms of pharmaceutical companies Abbvie and Merck, European-based investors Nextech, Inkef Capital and Droia Ventures and US-based investors RA Capital, Surveyor and Mission Biocapital, are specialized in biotechnology. "That is important," Brunsveld reflected. "Ambagon is still in an early phase and you want to work with investors who understand that it will take at least ten years for the research to develop, to mature the molecular glues into robust and effective medicines."

The road ahead

In *Innovation Origins*, his co-founder Ottmann said that things are currently going well for them. "We are busy developing our molecules in our preclinical studies where we test the molecules on human cells and, so far, it's looking very promising. We are starting to see the effects that we want. If this continues, then we can start taking the next steps and partner with pharmaceutical companies."

Brunsveld emphasized that the company's goal is not to develop a single, specific medication, but ultimately to create an entire platform. "Then, from that, we will continue to develop different types of medicines. Hopefully, within five years, we will have several clinical studies and projects underway in the field of oncology. Maybe even beyond that by then."

Endeavors that will potentially result in substantial financial gains, *Het Financieele Dagblad* suggested. Brunsveld was quick to dismiss making money as the main reason for the entrepreneurial efforts. "It is nice if there's money to be made," he was quoted, "but it's a long-term project and the chances of failure are significant." What does motivate him, he said, is that Ambagon provides him with the opportunity to improve upon his students' education in drug development. And, eventually, the chance to make new medicines available to the public. "It has always been my dream to contribute to something that can cure people."

Appendix A3 – Academic staff development plan

Academic staff development at BME: combining individual scientific visibility with collaborative strength

TU/e policy with respect to the (in)dependent position of their academic staff members (ASMs) has changed substantially in recent years. Whereas hierarchical collaboration between full professors, associate professors and assistant professors was the standard in the past, there is a strong push today to increase the visibility and scientific independence of young staff. While the ability of academic staff to develop their own independent research profile is broadly supported within the department, this also raises questions on how this will affect the organization of the department, how we can ensure the collaborative strength of the department and how we can accommodate and give room to different talents and career paths and value the different contributions of all academic staff members. This discussion has been ongoing for some time in the department without drawing definitive conclusions, which has also caused some uncertainties, especially among young tenure track (TT) academic staff. To come to a consensus and more clarity, the Department Board has asked the BME Science Committee for advice on these matters, using the position paper 'Academic staff at TU/e' of the Meijer interdepartmental committee as a starting point for their discussion. Their recommendations were discussed with the full professors and others in the department. Based on these discussions, the BME Department Board has, in consultation with the full professors, formulated and instituted a new ASM organizational structure, which is explained herewith.

We agree with the BME Science Committee that the position paper 'Academic staff at TU/e' provides a good framework for academic staff development. An important aspect is to distinguish between scientific independence and organizational independence. First, full independence does not really exist, as we all share a common responsibility for the department's education and research. Moreover, to be successful, it is important that research groups work together closely, particularly around their joint responsibility for education and maintaining common infrastructure. At the same time, we believe that it is important for all ASMs to develop their own research profiles. The development of a recognizable scientific profile first of all acknowledges the individual ASM's contribution but is also important to attracting personal funding and becoming an attractive partner in research consortia. However, to be able to be competitive at the national and international level, both in scientific and translational output and in obtaining large research, close collaboration between research groups in the department is also important. This close collaboration and coherence is supported and promoted by the department via the shared labs and infrastructure, the organization in clusters and a joint responsibility when attracting new ASMs.

The Science Committee identified a number of risks and open questions that required further discussion and decisions. Please find below how the department will deal with these issues.

TT assistant professor

- A TT assistant professor will have a senior staff member (full professor or associate professor PI) as their supervisor/coach. The main task of the supervisor will be to coach and help the TT assistant professor become successful in establishing their own line of research and also in developing other skills (leadership, education, etc.). For this, the coach/supervisor should have sufficient first-hand experience. Establishing their own research profile can be achieved in different ways, by focusing on personal career research grants (Veni, Vidi, ERC) or by participating in more collaborative research grants with the senior staff members and/or others.
- Successful guidance of young ASMs is an important aspect of being successful as a senior ASM. The relationship between supervisor and TT assistant professor should be one of mutual acknowledgement of each other's knowledge, contributions and experience in which both stand to benefit.
- While TT assistant professors are not independent from an organizational perspective (dealing with HR, *ius promovendi*) and are partially protected from these duties, it is important to increase their scientific visibility and ownership. This includes publishing as the last author, publishing independently from their organizational supervisor, being visible to the outside world as a 'scientific PI' (website, communication) and scientific responsibility for handling research grants.
- All ASMs can act as independent supervisors of bachelor's students and master's students. Organizational aspects (number of students, etc.) are best organized at the group/cluster level and it is advised to have a mix of junior and senior staff members in graduation committees. ASMs will also be involved in organizational aspects and tasks at the level of the research groups and the cluster, with the level of involvement and responsibility depending on experience and expertise.
- While each TT assistant professor will have one senior staff member with organizational end responsibility, the embedding and connections of the young ASM within the cluster and department is also important. The definition of new TT assistant professor positions and their recruitment are the joint responsibility of the cluster and the Department Board. To further recognize young TT assistant professors in their role as academic faculty members, the Department Board will also interact with them directly, both in joint meetings with other TT assistant professors and in a yearly meeting with the dean.
- We expect all TT assistant professors to develop their own research profile and we do not hire TT assistant professors merely to support the research of senior ASM or teach. However, a distinguishable research profile does not necessarily mean separation from other research lines. All TT assistant professors should contribute and develop in education and research, but the weights can be different.

Other ASMs

- We will keep the assistant professor, associate professor and full professor categories and not use PI as a formal functional category. The current description of these functional categories will be updated to see whether they still suffice.
- An ASM can become an independent group leader at the associate professor level, which means that he/she will have an independent group and be fully responsible for it – financially, scientifically and academically, including *ius promovendi*. In matters of personnel and finances, they will interact with the department directly. Whether an ASM can and wants to do this is part of the discussion between the Department Board and the ASM upon promotion to UHD (1 or 2).

- *Ius promovendi* does not automatically mean that an ASM has an independent group.
- The department will allow for variety in the size of research groups. Some will have only one full professor or independent associate professor, others will have one full professor and several assistant professors and associate professors. The optimal group organization will be determined by the department in discussion with individual ASMs and clusters and could be different for different research fields as well as change over time.
- The Department Board will make an organizational chart of the department that makes clear the current organization in groups, clusters, etc. We have already discussed this with the currents ASMs that will be organizationally independent and responsible for their own group.
- The organizational chart is not fixed in time and will change as a result of new hires and the career development of individual ASMs. These aspects will be discussed as part of the promotion of BACs and with group leaders at their annual meetings with the Department Board. In addition, the Department Board will discuss with each ASM their role in the organization at least once every five years.
- The Department Board will, in consultation with the clusters, decide on the need for new ASM positions and their nature. When ASMs leave or retire, they will not be automatically replaced.

Appendix A4 – Overview of research groups

Presented as separate booklet

Chemical Biology cluster

Jan van Hest	Bio-Organic Chemistry
Patricia Dankers	Biomedical Materials and Chemistry
Luc Brunsveld	Chemical Biology
Menno Prins	Molecular Biosensing
Lorenzo Albertazzi	Nanoscopy for Nanomedicine
Willem Mulder	Precision Medicine
Maarten Merkx	Protein Engineering

Regenerative Engineering and Biomaterials cluster

Sandra Hofmann	Bioengineering Bone
Jan de Boer	Biointerface sSience
Jurjen Tel	Immunoengineering
Sandra Loerakker	Modeling in Mechanobiology
Keita Ito	Orthopaedic Biomechanics
Carlijn Bouten	Soft Tissue Biomechanics and Tissue Engineering

Biomedical Image Analysis and Modeling cluster

Frans van de Vosse	Cardiovascular Biomechanics
Peter Hilbers	Computational Biology
Josien Pluim	Medical Image Analysis
Richard Lopata	Photoacoustics and Ultrasound Laboratory
Tom de Greef	Synthetic Biology
Natal van Riel	Systems Biology and Metabolic Disease

Notes

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