Report for the research review of Biomedical Engineering

Department of Biomedical Engineering
Eindhoven University of Technology

Site visit	18 and 19 September 2023
Report	7 November 2023

megvanbogaert

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Preface

The assessment of the research at the Department of Biomedical Engineering (BME) (2016-2022) was carried out using the Strategy Evaluation Protocol 2021-2027 established by VSNU, NWO and KNAW. The research evaluation was based on the self-assessments written by the Department and Research Groups and the site visit. During the site visit, the committee had discussions with the Board of the Department, the research group leaders, young academic staff, several PhD candidates and one post-doc. Also, the laboratory facilities were visited. All discussions took place in and open atmosphere and friendly dialogue. The current evaluation report includes the assessment of the quality, societal relevance, and viability of the research at BME. In addition, specific aspects, like open science, PhD policy and education, academic culture, housing and infrastructure, human resources policy as well as diversity were addressed. Finally, the report makes recommendations for further development.

Professor John Jansen
Chair research evaluation committee
October 2023

Executive summary

The Department of Biomedical Engineering (BmE) at TU/e is focusing on integrated biomedical solutions by merging engineering with natural and life sciences. Research is organized into 19 groups across three clusters: Chemical Biology (CB), Regenerative Engineering & Materials (REM), and Biomedical Imaging & Modelling (BIM).

The Department's mission aims for scientific excellence through an engineering approach, emphasizing the contribution towards understanding diseases and enhancing diagnostics and treatments. A commendable open and collaborative culture exists within the Department.

In the evaluation period research collaborations have been amplified and certain research areas strengthened. Its strategies have led to increased academic staff, external funding, and collaborations, resulting in the growth of research areas and recognition through awards and grants. Notable achievements between 2017-2022 include staff growth, increased external funding and cross-disciplinary research promotion. There is a clear emphasis on multidisciplinary research and inter-departmental collaborations. Also, strong affiliations exist within the TU/e and nationally with entities like Maastricht UMC, Utrecht UMC, and others.

Housing and infrastructure challenges include the lack of laboratory space and uncertainty about where the Department will be housed during and after completion of the renovation of the Gemini building. The committee recommends strategic planning for accommodations, with a focus on a dedicated medtech/life science building.

The Human Resources (HR) policy seems to satisfy tenure-track researchers, but the process for tenure decisions requires clarity. The Department is encouraged to enhance diversity and inclusion, especially at higher positions. Retention strategies for female and international talent are recommended.

Research quality is assessed as very good to excellent, with researchers being recognized both nationally and internationally for their contributions. Interdisciplinary research, state-of-the-art facilities, and collaborations with hospitals and medical centers contribute to the department's success.

Societal relevance is evident through education, patent generation, and spin-off companies. The Department actively seeks to translate scientific insights into medical applications.

Open Science practices are mainly PI-dependent, with a department-wide strategy being recommended. The committee suggests the use of electronic lab journals and a clearer dissemination strategy.

Viability is strong due to the quality of the research, an open culture, and collaboration between the departmental board and group leaders. However, the lack of laboratory space and uncertainty about future housing pose significant threats.

PhD training and supervision are generally positive, with room for improvement in terms of formalization, milestones, and second supervisor involvement. A culture shift towards four-year graduation is recommended. Policy and career tracks require more guidance and transparency to support postdoctoral researchers.

Overall, the BmE Department demonstrates outstanding research and collaboration while facing challenges related to infrastructure and growth management. Recommendations include clearer departmental structures, a focused strategy on Artificial Intelligence (AI), and strategic changes in HRM. The challenges related to housing and laboratory space require immediate attention to maintain the department's unique culture and efficiency.

Introduction

Scope of the evaluation

The Executive Board of Eindhoven University of Technology (TU/e) commissioned a review of the research conducted in the Department of Biomedical Engineering. The review is part of the regular six-year quality assurance cycle of the university and is intended to monitor and improve the quality of the research and fulfil the duty of accountability towards government and society. The quality assessment in this report is based on the assessment system in the Strategy Evaluation Protocol for Public Research Organizations 2021-2027 (SEP, appendix 1) drawn up by the Universities of the Netherlands, the Dutch Research Council (NWO) and the Royal Netherlands Academy of Arts and Sciences (KNAW).

The review committee

The Executive Board of TU/e has appointed a review committee (hereafter: committee) of six external peers according to SEP. The committee consisted of:

- Prof. John Jansen (chair), Radboud University, Nijmegen (NL);
- Prof. Liesbet Geris, KU Leuven and University of Liège, Belgium;
- Prof. Kurt Vesterager Gothelf, Aarhus University, Denmark
- Prof. Sabine van Huffel, KU Leuven, Belgium;
- Prof. Twan Lammers, RWTH Aachen University Clinic, Germany;
- Ir. Anneke Schouten, PhD candidate TU Delft, NL.

The TU/e Executive Board appointed dr. Meg Van Bogaert as the secretary to the committee.

The evaluation criteria

The Standard Evaluation Protocol (SEP) was the starting point for the committee's evaluation. This protocol describes the objectives and methods for evaluating publicly funded research in the Netherlands. The SEP distinguishes three evaluation criteria: (1) quality of research, (2) societal relevance, and (3) viability. Additionally, the SEP asks committees to consider four specific aspects when evaluating the three central criteria. These aspects are: (1) Open Science, (2) PhD Policy and Training, (3) Academic Culture, and (4) Human Resources Policy. In addition to the guidelines and criteria in the SEP, the committee also considered its task established by the University Executive Board in the Terms of Reference. The Board requested the input of the committee on housing and infrastructure.

SARS-Cov-2 pandemic

The SARS-CoV-2-pandemic had a serious effect on the achievements of the Department between 2017-2022. The university buildings were closed for eight weeks, laboratory work had to be re-organized to meet the corona rules and interaction between staff members was hampered.

Information provided to the committee

The committee received the following information:

- Self-evaluation report;
- Group descriptions;

- Report previous research review;
- Strategy Evaluation Protocol 2021-2027.

Procedures followed by the committee

The site visit of the Department of Biomechanical Engineering took place on 18 and 19 September 2023. Before the site visit, the committee members were asked to read the documentation and formulate preliminary findings and questions for the interviews. During the site visit the committee had an open discussion with staff members, PhD candidates and Postdocs. The self-evaluation report of the Department and research groups was very informative and provided a comprehensive impression of the achievements and future developments.

Prior to the site visit, the committee received a presentation with an introduction to the SEP, specifics about the Dutch research landscape and the working methods. In an online kick-off meeting, approximately one week prior to the site visit, the committee agreed upon procedural matters. On the evening of 17 September 2023, the committee discussed its preliminary findings and prepared the site visit. During the site visit, the committee met with representatives of the Department and discussed its findings. To conclude the site visit, the committee presented the main preliminary conclusions to the Department. The schedule for the site visit is included in appendix 2.

This report describes the findings, conclusions, and recommendations of the committee. The Department is assessed based on its own objectives and strategies as well as in relation to departments and institutes worldwide in similar disciplines and on similar topics. The texts for the assessment report were finalised through e-mail exchanges. The final version of the report was presented to the Department Board, and Executive Board of the University for factual corrections and comments. The report was finalised on 7 November 2023.

Department of Biomedical Engineering

Organization

The Department of Biomedical Engineering (BmE) is one of the nine Departments of TU/e. In their research, the Department integrates engineering with natural and life sciences to develop coherent solutions to biomedical problems. Research in the Department is organized into 19 research groups headed by independent group leaders. Most groups consist of a group leader (Full or Associate Professor) and one or more Full, Associate or Assistant Professors with partial to full association with the group. The research groups are organized in clusters, i.e. Chemical Biology (CB), Regenerative Engineering & Materials (REM) and Biomedical Imaging & Modelling (BIM). In some clusters research groups closely align while in other clusters the research activities are more diverse. There are also strong interactions between clusters, with several researchers operating at the interface of clusters. Although the status of the clusters remains unclear to the committee, it agrees that the themes of the three clusters have been well chosen.

The Department has strong connections within the TU/e with the Departments of Mechanical Engineering, Chemistry and Chemical Engineering, Applied Physics, and Electrical Engineering. These strong connections are supported by the proximity of the buildings of the various departments. Several Biomedical Engineering members even have joint appointments and/or are members of the Institute for Complex Molecular Systems (ICMS). At the national level, the Department has strong connection with Maastricht UMC, Utrecht UMC, Radboud UMC and Wageningen University. In addition, the Department collaborates with the two Eindhoven hospitals, i.e. Catharina Hospital and Maxima Medical Center.

The Department is headed by the dean, two vice-deans and the managing director, who have bi-weekly meetings. Together, the dean and the two vice-deans cover the three clusters of the Department. The director of education and a student representative attend the bi-weekly board meetings as advisors.

The Department Board receives input from several advisory bodies, like the Department Council (assesses budget of the Department and major organizational and/or educational changes), Examination Committee (decides on all formal matters related to examinations and education), Program Committee (focuses on the implementation of the education program and examination regulations and provides solicited and unsolicited advice to the Department Board), Science Committee (advises the board on strategic matters related to research, career development of academic staff and selection of departmental research awards), and International Advisory Board (provides independent advice and feedback of the research and educational strategy of the Department).

The decision to formalize the independent organization status of associated professors was based on the recommendations of an interdepartmental committee and extensive staff discussions. Consequently, the research groups vary in size from a single academic staff member to groups with a full professor and several assistant and associate professors. The departmental academic staff is confident that this resulted in a clearer organization and meets their needs. The committee observed that the current

organizational structure of the Department has resulted in a very good internal working culture and atmosphere, as well as in collaboration between the different research clusters and research groups. Nevertheless, the committee is not per se convinced that the current strategy, which supports the possibility of academic staff members to become independent group leaders at the associate professor level, is to be preferred. While on paper the groups are independent, there is in practice a lot of interaction and collaboration. Although the committee is aware that there is always a natural turnover of academic staff due to retirement or leave, becoming an independent group leader with its own independent research profile, can lead to the need for additional academic staff if this new group leader is very successful in acquiring grants. In this context, the committee notices that growth cannot be unlimited, due to lack of financial resources. At a given moment, difficult choices must be made about which areas to prioritize in the future.

The departmental culture and way of collaborating are informal and have grown organically; the researchers know each other well, and fit into the culture, which ensures that the informal structure works effectively. For outsiders, such as newly appointed researchers and the committee, it is not easy to understand the structure and culture. The committee is of the opinion that the framing of various topics at the departmental level will ensure better visibility of existing coherence, for example, collaboration, and can provide a collective perspective on other topics, such as open science.

Mission and strategy

The multidisciplinary research field of biomedical engineering connects traditional engineering disciplines with the natural and medical sciences. The BmE Department aims 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. According to the self-evaluation report, the combination of engineering and life sciences positions the Department to make contributions to unravelling the pathophysiology of diseases and to enhancing the diagnostics, intervention, and treatment of these diseases. The scientific questions addressed are inspired by fundamental challenges in biomedicine and healthcare. The Department actively pursues 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 the staff.

The general mission of BmE strongly focuses on excellence. According to the committee, this allows a lot of room for the various research groups to define their own mission and strategy. It gives the group leaders significant say over the direction of their research, although – at the same time - it also results in a somewhat diffuse image at the department level. From a branding perspective, it is recommended by the committee to have a clear and coherent mission, reflecting the impressive collaboration that takes place within the Department.

Based on the recommendations of the previous assessment, the Department intensified strategic collaborations with several medical departments and bioengineering institutes. Further, existing research areas, such as molecular engineering, regenerative medicine & biomaterials, the photo-acoustics & ultrasound Imaging group and immunoengineering, were strengthened. The committee strongly supports that the Department further

intensifies their research by adopting the newest insights in machine learning and artificial intelligence.

Major strategical achievements between 2017 and 2022 were:

- Increase of academic staff and external funding: between 2017 and 2022, academic staff within the Department increased by 20%. External funding grew by 41% between 2017-12022.
- Cross-disciplinary research: TU/e made the strategic decision to support cross-disciplinary research. Biomedical Engineering played already a leading role in the Institute for Complex Molecular Systems (ICMS), which was further enhanced. Further, the BmE staff and research groups are participating in the newly established institute EAISI (Eindhoven Artificial Intelligence systems Institute) and in EAISI supported projects.
- Funding: the Department was very successful in obtaining European ERC grants, and participates in Gravitation programs and national private-public consortia (e.g. Regmed XB).
- Recognition and awards: the visibility and independence of young staff members was formalized by providing an independent organizational status to some associate professors, who now run their own group. In addition, each tenure track assistant professor was given a senior staff member (full professor or associate professor/group leader) as their supervisor/coach. Further, academic staff members were rewarded a Spinoza Prize, one Veni-grant, seven VIDI grants and one Vici-grant.

Academic culture

The committee commends the Department on the open atmosphere, including the sharing of knowledge and facilities. The employee satisfaction survey confirms that the staff is satisfied. Nevertheless, six percent of BmE employees experienced or observed some form of unacceptable behaviour, and similarly for academic misbehaviour. An effort should be made to analyse what is causing this and the Department should work on a departmental policy to prevent this and reduce this percentage.

Important for the functioning of the Department is the informal culture and the collaboration. It is impressive how well this works; the committee has the impression that the researchers support each other and grant something to others, even if they do not (directly) benefit from it themselves. At the same time, even though the open atmosphere is confirmed by junior and mid-career research staff, the committee has the impression that the senior staff members might overestimate their approachability for more junior, and - in particular - international staff. Providing a more formal structure might offer PhD candidates and postdocs, in addition to the open, personal way of working and addressing each other, an alternative way to raise potential issues. It is furthermore not clear from the organizational plan, who is responsible for the PhD candidates at a departmental level.

PhD candidates follow a Scientific Integrity course. Beyond the TU/e Code of Scientific Conduct, the committee did not encounter explicit policy regarding research integrity. The committee is of the opinion that the degree of interdisciplinary collaboration supports good research integrity. The committee thinks that research integrity can be improved by the Department-wide implementation of electronic lab-journals.

Housing and infrastructure

The Department is currently housed in several buildings on the TU/e campus, with two main locations. A strength of the Department is the shared research laboratories, which is an outstanding way of promoting collaboration and interdisciplinary research. The sharing of (expensive) equipment also ensures efficient use of limited departmental budgets. It furthermore enables a fast start of new research and researchers. Although it is not optimal that the Department's research groups and clusters are housed in different buildings, the distances between them are relatively short and researchers are aware of the added value of actively seeking each other out. Ideally, the Department would be housed in a dedicated medtech/life science building on campus, together with (parts of) other departments. Such a committed building will strengthen the research and its technological as well as societal impact, which is in line with the university's strategy. At the same time, it makes sense to ensure close physical connection between e.g., the Chemical Biology cluster groups and related groups in the Chemistry Department.

The research facilities of the department are state-of-the-art facilities, which are shared among all research groups. Maintenance of the state-of-the-art facilities is a challenge, both from a financial and organizational perspective. A department facility manager was hired with responsibility for overall operational management and strategic development. However, the steady increase in employees and students in the past evaluation period, was not accompanied by a similar growth in m^2 of laboratory space. This leads to intensified use of laboratories and – on occasion – lack of availability of specific equipment. Also, the growth of technical support staff seems to lag and the current combination of BSc and MSc course training and state-of-the-art research in the same laboratories is far from ideal. It affects safety in the cell labs (use of dangerous chemicals, more risk for contamination), and requires night or weekend work when equipment is overbooked (e.g. microscopes). Moreover, the PhD researchers cannot work efficiently because of excessive requests for help by bachelor and master students. Safety training (including chemical safety) is recommended for all users.

Some researchers have grants that include dedicated support staff. While this is very convenient for individual projects and researchers, it does not help in the sustainable maintenance and joint use of facilities. Equipment maintenance is partly regulated by super-users, intensive users who have extensive knowledge of a specific piece of equipment, or microscope. These super-users - often PhD candidates - indicate that managing equipment that is intensively used - often by bachelor's and master's students - can be time-consuming.

The two main buildings in which the Department is housed, i.e. Gemini and Helix, require renovation in resp. 2025 and 2030. The current plan is to move research staff and laboratories to temporary housing outside the campus while the buildings are being refurbished. However, in the planning phase of the renovation of Gemini, the required laboratory space was estimated much lower than is considered realistic in 2023, at the time of the site visit. This building is shared with the Department of Mechanical Engineering and growth in student numbers and research staff of both departments are much higher than estimated and further growth in the coming years is plausible. This results in uncertainty about the situation after renovation, with the fear that the temporary accommodation will become permanent. This potentially has negative impact on the research quality, and it may make the Department less attractive to talented and established researchers. This current situation of uncertainty about the future housing is

highly undesirable to the Department. The committee strongly agrees with this notion and is of the opinion that clarity is required. In the short term, TU/e should make choices for future accommodation based on realistic scenarios.

Despite the current challenges regarding laboratory space and uncertainty about future housing, the committee also sees a huge opportunity. If TU/e is indeed to have health as one of its central themes, now is the time to make accommodation choices that will contribute to this theme in the long term.

Human Resources Policy

Overall, the tenure-trackers (TT) seem to be satisfied. Although workload is high, they experience an open work climate and a large degree of autonomy, as confirmed by a high score 4.2/5 of satisfaction in a recent survey. They appreciate having scientific independence and the freedom to develop their own research line. Shared lab-facilities are a major advantage for this group, despite TTs not having their own lab facilities and dedicated support staff.

TU/e has designed a tenure track system in which the decision on tenure is made after four years. Recently there is a growing push for more permanent positions in the academic system, as also agreed in the most recent collective labour agreement. The committee therefore understands the plans to give tenure at an earlier stage and implement a career track system. The requirements for tenure – unlike for promotion to associate professor - are somewhat vague, although the candidates feel that the midterm evaluation provides insight into their development. The developments in *Recognition and Reward* are leading to more personalized plans and goals for individual tenure trackers. The tenure trackers have a council that regularly meets.

Diversity

At student and PhD level, the gender balance is good. The Department also puts a lot of effort on improving gender balance at higher positions. Unfortunately, only one third of the tenure trackers is female and even less at professor level. In addition to several male academic staff leaving, several female staff members left due to various reasons between 2017 and 2022. Therefore, continued attention is needed for the recruitment and retention of female staff. In addition to recruitment, the Department should focus on retention policy to retain female and international talent.

Research quality

According to the committee, the quality of the research of the Department is very good to excellent, based on the important research topics addressed and on the very high-quality level of scientific output. The 19 research groups are all led by very good to excellent and ambitious leaders, who are provenly able to attract prestigious grants and recognition to perform their research and producing outstanding scientific output. Close to all research groups are frequently publishing in top-tier journals. The quality of the research is further evidenced by multiple collaborative publications by PI's from different groups and clusters. The number of publications and PhD theses was increasing between 2017-2021, but was reduced in 2022. The committee understands that the SARS-CoV-2 pandemic had an impact on these numbers in 2022.

The committee was pleased to learn that academic staff is well represented in the Eindhoven Young Academy (EYAE) and KNAW. The work of many PIs is funded national and international; individual and in consortia by prestigious grants from respected organisations, such as ERC and NWO (Talent and Gravitation programme). Multiple PI's are recognised as global leaders in their field and have received prestigious awards. In addition, several staff members are (associate) editors in highly valued peer-reviewed international journals. This all contributes to the outstanding reputation and international visibility of the Department.

The committee observed that the research groups are successful in doing interdisciplinary research. Presence and participation in the ICMS indeed confirmed that the collaboration is successful. Considering the laboratory facilities, all research groups make efficient use of the space, with everybody having access to all facilities, which is beneficial for young, tenure track researchers and is stimulating the interaction between research groups.

The collaboration with various local hospitals and University Medical Centres (UMC's) is further evidence of the outstanding quality. The committee feels that, based on the meetings with representatives of the three clusters, the absence of a University Medical Centre in Eindhoven cannot be confirmed as being a weakness. In fact, it can even be seen as an opportunity to opt for specific collaboration with one of the local hospitals, or a UMC. New connections and collaborations will require some time and effort, but the committee expects that this can be facilitated by using the networks already available within the Department.

Cluster Chemical Biology

The *Bio-Organic Chemistry* group specializes in the synthesis of bio-inspired materials, particularly micro- and nano-capsules, for advancements in nanomedicine and artificial cell research. Applying techniques from polymer science, protein engineering, and conjugation chemistry, the group has developed structures that mimic biological systems. Notable achievements include the creation of polymersome nanoreactors with transient, life-like features and the development of nanoparticles for improved therapeutic efficacy in cancer treatment and immunology. The work has been published in several high impact journals such as JACS, ACIE and Nat Commun. Furthermore, the group has developed biomaterials for haemostasis and tissues adhesion which have been commercialized. The group has collaborations with other institutions and has also introduced new expertise through new members. The above observations underscore the groups strong research quality and potential for future contributions in the realm of bio-organic chemistry.

The *Biomedical Materials & Chemistry* research group at the Institute for Complex Molecular Systems is conducting research in the field of supramolecular polymer chemistry and regenerative medicine. They have utilized ureido-pyrimidinone (UPy) moieties to craft biocompatible supramolecular biomaterials, which have shown great promise for medical applications, particularly in kidney regeneration. Their work has led to pioneering contributions, such as the development of a 3D printable kidney proximal tubule, a significant advancement in regenerative medicine. Their collaborative efforts with both academic and industry partners underscore the translational potential of their research. The work has resulted in several publications in top journals such as Adv Mater. The group's commitment to innovation is further exemplified by their efforts in founding

start-ups like UpyTher (2020) and VivArt-X (2022). The convergence of high-quality research, practical applications, and entrepreneurial ventures demonstrates the quality of the research in this group.

The *Chemical Biology* group strives to bridge molecular science and biomedical applications. The team seeks to understand and modulate protein-protein interactions by employing a diverse set of expertise ranging from organic synthesis to machine learning. Noteworthy achievements include pioneering efforts in the combination of synthetic supramolecular systems with chemical biology, advancing knowledge in nuclear receptor chemical biology, and stabilizing so-called 14-3-3 mediated protein-protein interactions, a distinct move when many were focusing on inhibiting such interactions. Their commitment to clinical translation and biotech entrepreneurship is evident through numerous collaborations with industry giants and clinical partners, as well as the creation of Ambagon Therapeutics, a successful biotech start-up. The group's dedication to research quality is further underscored by significant grants such as recently awarded ERC Starting and Advanced Grants. The listed key publications and patents from the evaluation period emphasize impactful contributions to the field.

The focus of the *Molecular Biosensing group* is the development of innovative sensing technologies for real-time, continuous biomolecular monitoring. The group has pioneered the novel particle-based biosensing technology known as Biosensing by Particle Motion (BPM). This technology has consistently demonstrated its applicability across a range of biomolecules and concentration levels, as evidenced by prominent publications in esteemed journals such as Nat Commun and Nano Lett. Their significant advancements in the realm of single-molecule resolution and label-free biophysical measurement principles highlight their leading position in the domain. Coupled with a series of patents and a successful spin-off company, Helia Biomonitoring, the group's scientific contributions have the potential to make transformative impacts in fields ranging from biotechnology to patient care.

The *Nanoscopy for Nanomedicine* Group is utilizing advanced optical imaging techniques for innovations in nanomedicine, diagnostic, and precision medicine. They use state-of-the-art single-molecule imaging techniques methods like STORM and PAINT. The group's research direction includes: (i) developing new microscopy methods for detailed nanomaterial characterization, (ii) employing super-resolution microscopy to refine the design of new materials, and (iii) establishing nanoscopy-based tools specifically for cancer diagnostics. The group has made notable advances in technology development, as showcased by their work on correlative light-electron microscopy and automation to enhance super-resolution microscopy. In nanomaterials characterization, they have been instrumental in developing imaging techniques for nanoparticles. Furthermore, their advancements in super-resolution diagnostics have initiated steps toward clinical applications, especially in tailoring treatments for cancer patients. This research quality is underscored by key publications in esteemed journals such as JACS, Nano Lett, and Nat Chem Biol.

The *Precision Medicine* Group works on nanobiologics and nanoimmunotherapeutics. The group’s research, which also encompasses efforts at the Radboud University Medical Center, emphasizes preclinical evaluations of novel immunotherapeutics using an array of disease models. The group has applied lipoprotein-inspired therapeutic delivery and has established three main research themes, each supported by dedicated teams. These

areas are 1) Apolipoprotein nanoparticles for RNA delivery to leukocytes and their progenitors, 2) Apoprotein engineering for immunoregulation and targeting and, 3) Hydrogel platform for local immunoregulation. Their scientific contributions are evident from multiple high-quality publications, including works in leading journals such as Nat Biomed Eng, Nat Nanotechnol and Cell. Aside from scientific outputs, the group shows a commitment to societal impact and commercial translation, as seen through their intellectual property liaison with BioTrip and their educational outreach efforts.

The *Protein Engineering* group is focused on integrating chemical and synthetic biology for biomolecular engineering and diagnostics. Their work stands out particularly in the domain of bioluminescent sensor proteins for point-of-care diagnostics, protein-DNA biomolecular switches for diverse applications, and FRET-based fluorescent sensors for transition metal ions. The group's innovations have been instrumental in advancing point-of-care diagnostic tools, especially the development and application of the LUMABS platform and its subsequent adaptations. Their publications in high-impact journals and consistent efforts in technology commercialization through a start-up, LUMABS BV, underpin their research quality. Collaboration with renowned institutions and the translation of their research into viable diagnostic tools further show the group's significant contributions to the field. Their prospects, leveraging AI and deep learning in protein engineering, promise continued advances and relevance in biomedical research.

Cluster Regenerative Engineering and Materials

The *Bone Bioengineering* group became independent in 2021. Their research focused on the development of 3D bone tissue model systems and 3D printed scaffolds. They published the outcome of the research in well-respected peer-reviewed international journals. The future of the group is uncertain, as the group leader is leaving. Consequently, they will discontinue further development of 3D bone tissue models. In addition, the bone engineering field is nationally and internationally highly competitive. This questions the viability of the research group considering its small size and supports the need of attracting a new group leader (Full Professor/Associate Professor) or incorporation of this group in one of the groups of the Regenerative Engineering Cluster.

A major effort in *Biointerface Science* was the development of the TopoChip and a digital microfluidic platform, allowing a high-throughput pre-clinical screening of the cell-material response. This research is highly relevant for the further development of implants and biosensors. Important for the future is that the model systems are validated under in vivo conditions for further translation of these model systems to the clinical situation.

The *Immunoengineering* group is performing impressive work to understand immune reactions by combining systems biology, microfluids, single cell analysis and engineering. The final aim is to implement the developed technology for personalized medicine of patients suffering from auto-immune disease as well as improving immunotherapy. Therefore, the research group cooperates with companies as well as hospitals. Although, the current funding of the research group is sufficient, future funding is not secured yet. Considering the complementarity of the *Immunoengineering* and *Precision Medicine* group it is not clear why these groups do not corroborate with each other or are even merged. This will make their national and international position even stronger.

The *Modelling in Mechanobiology* group became independent at the end of 2019. Their major effort is focused on computational modelling of soft-tissue response in the context of cardiovascular tissue engineering. The research fits well in the Regenerative Engineering Cluster and provides clearly added value. For the next period, the focus is shifting to the computational modelling of inflammatory-mediated tissue regeneration, which can be considered of a well-chosen and state-of the-art topic.

The *Orthopaedic Biomechanics* research group has an excellent national and international reputation. They have a strong and impressive research profile. The valorisation and societal impact of the research is excellent. The considerable size of the group and the excellent funding position makes they are ready for the future. In addition, there is involvement of a clinician in the research.

The *Soft Tissue Engineering and Mechanobiology* research group is one of the top groups of the Department of Biomedical Engineering. The research output, funding position, knowledge transfer and societal impact are all excellent and evidenced by the achievements. The only minor concern is that, because of their success, two academic staff members might start their own independent research group in the coming period as was suggested in the self-evaluation report. Although, the group leader can undoubtedly manage this, it is now difficult to assess if this will have a positive or negative effect of the research group.

Cluster Biomedical Imaging and Modelling

The research group in *Cardiovascular Biomechanics* does impressive research and is internationally renowned. Important for the future are the generation of virtual cohorts, uncertainty quantification and sensitivity analysis regarding model output and assumptions, focusing on patient-specific models and personal medicine. The research on hybrid models combining physics-based models and data-driven models is original and future oriented. A wide variety of health relevant applications are successfully tackled with diverse clinical partners and/or international consortia. However, viability is uncertain due to the retirement of the group leader and the self-evaluation report did not mention the plans for recruitment of a successor. After the site visit, the committee was informed that a candidate for this position was recruited in 2023. The committee emphasizes that the leave of an important staff member building his own group and multiple moves of full professors with an appointment of zero fte, as well as the necessary funding of 12-15 PhD candidates to maintain sufficient critical mass in research, is a potential threat since the competition in this field is growing as the result of the initiation of other cardiovascular biomechanics groups in the Netherlands.

The research group in *Computational Biology (CBIO)* focuses on computational modelling methods from molecular and cellular levels to reveal cell metabolism and transport mechanisms. The impact of the split of the group in 2019 into three independent research groups - due to the promotion of two staff members – is unclear to the committee. These fields are strongly connected, and the groups might become too small to ensure future funding. Moreover, due to the retirement of the group leader in 2023, one former staff member will again enter CBIO as new head. The committee wonders if these organizational changes are beneficial for the quality of the research.

The *Medical Image Analysis* group focuses on all aspects of medical imaging methodology and clinical applications. Their connection with UMC Utrecht is a major strength. The efforts to provide open databases and open-source code is very much appreciated by the committee. Important research foci with major clinical value are synthetic image generation using deep learning to reduce the need for large real-life datasets, as well as making image tools scanner-independent. Translation to the clinic is important focusing on serious issues w.r.t. interpretability and generalizability of the AI tools. However, the leave of several staff members (two left, one leaves in the upcoming period) might make the group vulnerable and leads to questions on future funding (description missing) to stay at the forefront of AI-based medical imaging.

The *Photacoustics and Ultrasound Laboratory (PULS/e)* group started in 2019 and is a young ambitious and very successful team focusing on the development of novel photoacoustic and ultrasonic imaging modalities (hardware and software) up to their validation in clinical decision support. The group has an extensive clinical and industrial network with an outstanding track record in funding (personal grants, local and (inter)national projects), ensuring their viability for new research lines.

The *Synthetic Biology* research group - with only one staff member but expanding soon with one UD-2 - develops new biological systems as a technology. Synthetic Biology (SB) was between 2017 and 2022 oriented to prototyping cell-free genetic networks but shifts now slowly to mammalian SB. DNA Nanotechnology focuses on building a compartmentalized DNA-based molecular computer resulting in successful collaboration with Microsoft Research. The group leader has an outstanding publication record with multiple Nature papers and attracted impressive funding channels (multiple ERCs, NWO, 4TU Alliance), even spinoff activities, and continues to apply even for larger grants in bigger consortia (NWO SUMMIT, Groeifonds) to expand further along new research lines.

The *Systems Biology and Metabolic Disease* group started in 2019, but now reintegrates into CBIO after the retirement of its head and takes over one tenured academic staff member. The committee wonders whether these organisational changes are beneficial. Research is focused on two themes and targets clinical applications: metabolic network models integrating heterogenous datasets such as multi-omics data, and dynamic models of human metabolism and its multi-level regulation. Further expansion towards hybrid modelling combining knowledge-based models with data-driven machine learning is very promising for the development of patient digital twins. Therefore, the group should invest in enough knowhow in AI and data science technologies and major funding channels (ERC and NWO grants) to prove enough viability for their 4 future research lines.

Societal relevance

The Department mainly addresses societal relevance in the context of education, patents, and spin-offs. Significant and increasing numbers of bachelor's, master's and PhDs were trained. Although teaching is part of a university, the Department contributes to the high demand for experts in BmE. The Department invested in a renewed bachelor's curriculum including more hands-on and blended education, as well as more focus on AI and data sciences. Additionally, first plans are made for joint medical bachelor's and master's programme with UMC Utrecht to educate medical doctors with an engineering background. These discussions are facilitated by a strengthening of the collaboration with Utrecht and an increase in joint professor appointments.

The Department strongly focuses on translation of innovative science into medical applications like new or improved therapies and diagnostics. The Department has strengthened its connections to university medical centers and the Dutch Cancer Institute via joint appointments. In addition, the Department was highly successful in initiating spin-off companies, and consolidating public-private partnerships (PPP). The establishment of *The Gate*, which provides support and facilities for start-ups in the Brainport region, has contributed to this increase in patents and spin-offs, which was confirmed by group leaders. The Department's academic staff can invest time in setting up a start-up. In doing so, clear agreements on time investment and knowledge transfer are made at the start. The previous committee recommended to improve the IP strategy. Evidently, the self-evaluation report confirms that the number of patents significantly improved during the current review period.

Open Science

Concerning open access publications and sharing of data, the Department does very well with over 90% open access publications. Analysis algorithms, software and databases are made publicly available through public repositories or various GitHub pages.

The approach to and implementation of Open Science appears to be very PI-dependent. Policy on data-management planning etc. is organized at university level, and a specific translation at Department level seems to be lacking. The data-steward that was appointed might play a stimulating role in the department-wide approach. One explicit recommendation by the committee is to move entirely to the use of electronic lab journals.

The committee has a similar observation regarding outreach, for which the approach is very PI-dependent. The involvement of stakeholders– again –differs between the research groups. The committee considers stakeholder involvement a department-wide opportunity, given the relevance of biomedical engineering in technology-based healthcare. A clearer departmental strategy for dissemination towards the public is therefore recommended. The recommendation is to get together and discuss this issue, both cluster and department wise, learn from each other, and jointly develop an intra-departmental strategy. This does not mean that all research groups need to be active in all aspects, but that the Department has a strategy, direction, and results. This makes the Department more visible and therefore more appealing to potential investors.

Viability

The committee appreciates the SWOT analysis made by the Department. As mentioned above, the weakness of not having a UMC in Eindhoven is properly dealt with. Furthermore, in the self-evaluation report the Department recognises that Artificial Intelligence (AI) should be at the forefront of the research in the upcoming period. The committee agrees and recommends that the Department puts even more and explicit focus on AI and on strengthening its position of AI in health, e.g. with a leading role in the to-be-developed Technical Medical Center Eindhoven, or in institutes such as EAISI.

Based on the high quality of research in the recent period and its open and collaborative culture, the committee assesses the viability for the Department as outstanding. The success and growth of the Department in the evaluation period has been strengthened by the close collaboration between the departmental board and the group leaders.

Investment in new research directions is achieved through the recruitment of new academic staff members in consultation with the programme leaders in the three clusters. The relatively informal way of organization and collaboration within the Department seems very effective and appreciated. Despite this success, the committee feels that significant further growth in combination with the obvious lack of space could jeopardize this unique culture and efficient way of working. One illustration of the lack of space is the requirement to combine undergraduate course training with advanced research in the same laboratories. This arrangement may not be optimal for maintaining high research quality.

In the SWOT analysis, the most prominent threats also arise from the status of housing and laboratories, as extensively described on page 12-13 of this report. The committee emphasizes that the lack of concrete plans and decisions on what will happen during and after the relocation to temporary housing, is a very serious threat for the existence and further development of the Department. This unsolved situation also creates a lot of uncertainly among the employees at the department. The committee understands the department's desire for a dedicated medtech/life science building. As a focus area of the TU/e, this offers immense opportunities in the long term. The committee does conclude that the current situation is inadequate and emphasizes the importance of a decision in the short term by the TU/e and clarity for the Department and its researchers.

PhD policy and training

According to the committee, there are multiple good aspects in the PhD training and supervision. A lot has been initiated and achieved in this regard in the past few years. The use of the Training and Supervision Plan (TSP), with yearly assessments and a clear go/no-go decision at nine months are aspects that - especially among the more recently started PhD candidates - are well applied. The dean has exit interviews with all candidates to get input on where improvements can be made. Recently, the dean - together with HR - also conducted interviews with PhD candidates in their first year. In addition, the committee is positive about the close collaboration with supervisors. Overall, PhD candidate’s satisfaction is high, which is also reflected in the employee satisfaction survey conducted. The re-establishment of a PhD council is a positive consequence of preparations for this review. The committee stresses the importance of PhD representation and supports further development of the PhD council.

The committee does recommend the further implementation of Hora Finita to better formalize the follow-up of the progress made by the PhD candidates (e.g., include automatic reminders), requirements for a dissertation and expected milestones to be reached. This includes timely appointment of a second supervisor, standardization of the annual performance meetings, and expectations on publications and teaching. It is strongly recommended to have a Department-wide written document on the structure and framework of a PhD, including the expected milestones. A minimal set of requirements should be in place for all PhD candidates and should be clear; this will give them a sense of control and structure. Finally, the committee calls for attention to the support of PhD supervisors. Beginning supervisors should learn how to deal with PhD candidates through training and/or coaching. It is not just about guidance on the research, but especially on how to deal with the personal supervision and wellbeing of the PhD candidate.

Despite the formal requirement, not all PhD candidates seem to have a second supervisor who is regularly involved in the process and progress. This makes the PhD candidate very dependent on the first supervisor. Although interaction and supervision usually go well, the committee considers this situation as highly undesirable. Therefore, the committee urges the Department to involve an external and/or neutral person in the annual evaluation of PhD candidates, or to find another way to have PhD candidates regularly meet with an independent mentor or PhD counsellor. A similar observation holds true for the exit interviews. These are clearly relevant, although a more formal structure, including an independent interviewer, may help to ensure the PhD candidates to feel safe and open up.

The previous committee was concerned about the duration of the PhD trajectories; it is difficult to establish if this has improved due to the SARS-CoV-2-pandemic. Group leaders indicated that delays are rare, although several PhD candidates receive extensions for various reasons. The committee stresses the importance of graduating in four years, in order not to hamper the next step in the careers of the PhD candidates. The norm should be four years; this may require a culture change, both among PhD candidates and supervisors.

Information on postdocs is missing in the self-evaluation report. A clear policy and career track for postdocs seems to be lacking, which was confirmed in the interviews with the committee. More guidance and transparency on their role and future career expectations are recommended.

Recommendations

Academic culture

The open atmosphere is a positive feature of the Department and confirmed by junior and mid-career research staff. Nevertheless, senior staff members might overestimate their approachability for more junior and, in particular, international staff. By providing a more formal structure, PhD candidates and postdocs have an alternative way to raise potential issues.

The committee recommends that an effort should be made to analyse what is causing that six percent of BmE employees experienced or observed some form of unacceptable behaviour, or academic misbehaviour. Subsequently, the Department should work on a policy to prevent this behaviour.

Housing and infrastructure

The current laboratory situation of combination of undergraduate course training and state-of-the-art research in one laboratory is far from ideal and affects safety in the cell labs. The main buildings in which the Department is housed require renovation and currently it is estimated that the laboratory space after the renovations will be insufficient. Clarity on the future housing is required, the committee stimulates TU/e to make choices for future accommodation in short term and based on realistic scenarios. Ideally, the Department will be housed in a new, dedicated medtech/life sciences building on campus with (parts of) other departments.

Equipment maintenance is partly regulated by superusers – often PhD candidates – who indicate that managing equipment is very time-consuming. This might require regulation by the Department.

HRM

The requirements for tenure are somewhat vague. Although candidates feel that the midterm evaluation provides insight into their development, requirements could be made clearer. This can be combined with the further development of the Recognition and Reward initiative, which is leading to more personalized plans and goals for individual candidates.

The Department should not only focus on a policy of hiring, but also on retention policy for female and international talent.

A clear policy and career track for postdocs seem to be lacking. More guidance and transparency on their position and future career expectations are recommended.

Societal relevance

A clear departmental strategy for dissemination research results towards the public is recommended. Also, a department-wide implementation of electronic lab-journals is stimulated.

Viability

The Department is recommended to put even more and explicit focus on AI and on strengthening its position of AI in health.

The informal way of organization, collaboration and communication is appreciated by staff and seems effective. Further growth, in combination with the obvious lack of space, could jeopardize this unique culture and efficient way of working. The committee recommends that the Department works on finding ways to continue the current culture and way of working, which might require a more formal organization.

PhD training and policy

The committee recommends the further development of the PhD council to stimulate PhD representation. It is furthermore important to continue the implementation of Hora Finita to better formalize the follow-up of the progress made by the PhD candidates. It is strongly recommended to have a Department-wide written document on the structure and framework of a PhD, including the expected milestones. PhD supervisors should be supported and trained/coached to provide qualitative supervision, e.g. on how to deal with the personal supervision and wellbeing of the PhD candidate in addition to supervision of the research.

The committee urges the Department to find a way to have PhD candidates regularly meet with an independent mentor or PhD counsellor, e.g., to involve an external and/or neutral person in the annual evaluation of PhD candidates. Also, the exit interviews are a positive development that could further benefit from a more formal structure and independent interviewer.

The committee stresses the importance of graduating in four years, in order not to hamper the next step in the careers of PhD candidates. It might require a culture change among both PhD candidates and supervisors to make four years the norm.

Appendices

Appendix 1 Sit visit programme

Sunday September 17th

Time	Who/what
	Arrival in Eindhoven
19.00-20.00	Meeting of committee
20.00-22.00	Committee dinner

Monday September 18th

Time	Who/what
8.45	Arrival at TU/e
9.00 – 10.15	Welcome by board, dean, vice-dean and director of education, Introduction of the department and information on programme of these days
10.30 – 11.30	**Cluster Regenerative Engineering and Materials**
11.45 – 12.45	Meeting **Young staff members** (8 persons) *1
12.45 - 13.30	Lunch, Committee only
13.30 – 14.30	**Cluster Biomedical Image analysis and Modelling**
14.45 – 16.00	**Visit the labs**
14.45 – 15.30	Visit Laboratory for Cell & Tissue Engineering - Including 3D print
15.30 – 16.00	Visit PULS/e
16.00 – 17.30	Reflection time
17.30 – 19.00	Time to transfer to hotel, refresh
19.00 – 21.30	Dinner with **group leaders** of the department

Tuesday September 19th

Day / Time	Who/what
8.45	Arrival at TU/e
9.00 – 10.15	**Visit the labs**
9.00 – 9.30	Visit Ceres (home of ICMS)
9.30 – 9.45	Transfer to Helix
9.45 – 10.15	Visit Laboratory for Chemical Biology
10.15 – 10.30	Transfer back to Gemini
10.30 – 11.30	Meeting **PhD students and postdocs**
11.45 – 12.45	**Cluster Chemical Biology**
12.45 – 13.15	Lunch, committee only
13.15 – 16.00	Time for writing / discussing / preparing first reflection. Optional, meeting staff members that have indicated to want this
16.15 – 17.00	**Presentation of first impressions** to the department

Appendix 2 – Quantitative data on research unit

Table 1: Development of 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 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.