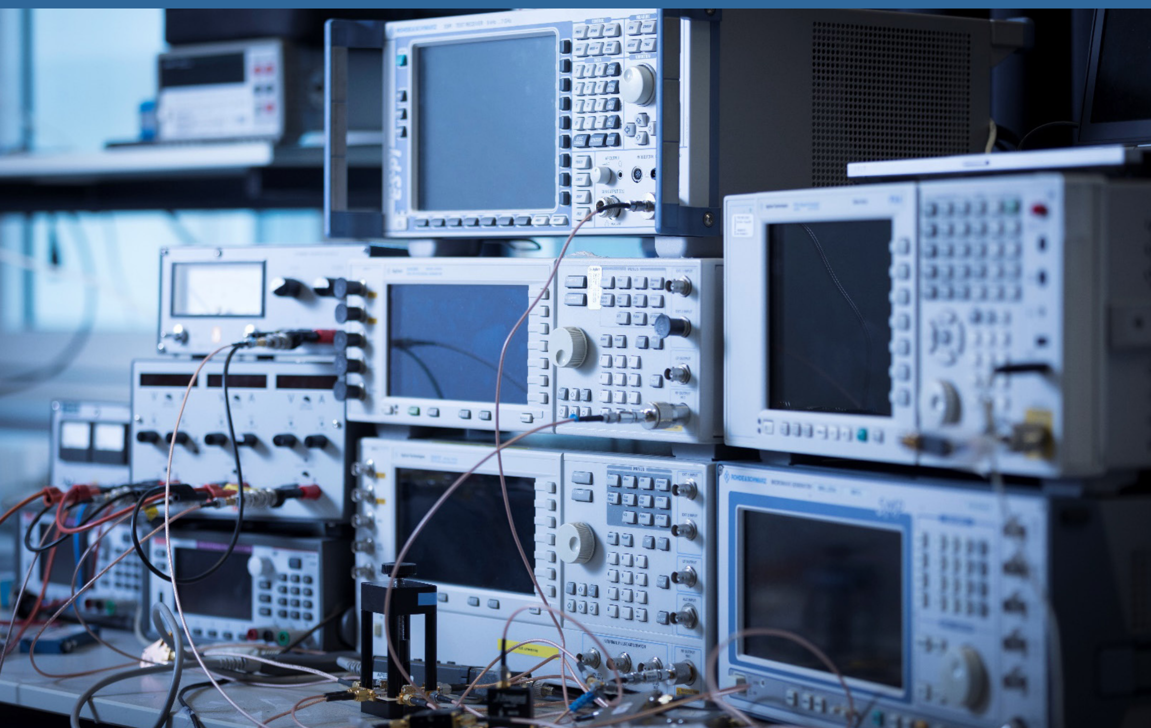
Assessment Committee Report on Research in Electrical Engineering 2011-2016

Delft University of Technology
Eindhoven University of Technology
University of Twente



March, 2018

ASSESSMENT COMMITTEE REPORT ON RESEARCH IN ELECTRICAL ENGINEERING 2011-2016

DELFT UNIVERSITY OF TECHNOLOGY
EINDHOVEN UNIVERSITY OF TECHNOLOGY
UNIVERSITY OF TWENTE

MARCH, 2018

Colophon

Title
Assessment Committee Report on Research in Electrical Engineering 2011-2016, Delft University of Technology, Eindhoven University of Technology, University of Twente

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PREFACE

Electrical Engineering has changed the world in the last sixty years thanks to its ability to put into practice major inventions. For many fields, electrical engineering provides enabling technologies, but it has shown strong parallel innovation dynamics all by itself as well. From a perspective of the 60's or 70's of last century, one would not recognize the computers, telephones, MRI scanners, HVDC transmission lines, electric cars, smart grids, photovoltaic cells, DNA analysis equipment, laboratories on a chip, and so on, we have today. And the perspective for innovation does not stop at what EE can do today. Major technological issues loom large before us. We need much finer and more accurate medical equipment, a total rethinking of mobility and transportation, integral sustainable energy production, much improved security, ways of dealing with our environment in a biologically responsible way and much more. This will require ever improved means, many of which will be provided by a clever interplay between electrical engineering and other fields.

The Domains in electrical engineering at the three Dutch Universities of Technology are at the forefront of engineering research in many areas where innovation in electrical engineering is critical for the development of the systems, industrial products and engineering practice our world and Dutch society in particular need for their future well-being. These Domains produce the next generations of engineers and equip them with the expertise needed to make them effective for technical competition in our globalized world, where quality and innovation are what make products and systems fly.

To assist the Dutch Technical Universities in charting the future of their Domains of electrical engineering, an international Committee has been constituted and has been given the task to assess the performance of the Domains in the last six years as well as their viability for the coming years, and to provide the Technical Universities with advice on how to chart their scientific future. Writing for the Committee, it has been a privilege to be given this task, to receive first-hand information on the proceedings of these three Domains, to be allowed to interact with all their research units, and to participate in their forward thinking about how to best address the future needs of Dutch and European society in knowledge and expertise in the crucial and extremely fast evolving field of EE.

This report gives an account of the Committee's activities, and offers conclusions and recommendations. It is the result of an intense and productive collaboration between all the parties involved. As its chairman, I wish to thank all the contributing parties for their open, effective and constructive participation. In the first place the members of the Committee and its secretary, next all the scientists who were involved in producing all the data and the insights, the organisers at the three locations, who took very good care of our strenuous schedules, and our commissioning authority (the joint Technical Universities of the Netherlands) for its confidence and support.

Prof. Dr. Ir. Patrick Dewilde
Chairman of the Committee

1. Assessment Committee and Assessment Procedures

1.1 Assessment Scope

The Committee was asked to assess the research of Electrical Engineering at Delft University of Technology (TUD), Eindhoven University of Technology (TU/e) and University of Twente (UT). More specifically, the Domains[1] to be reviewed as requested by the Executive Boards of the respective Universities and set in the Terms of Reference, are as follows:

- The Domain of Electrical Engineering at the Faculty of Electrical Engineering, Mathematics and Computer Science, Delft University of Technology;
- The Faculty of Electrical Engineering, Eindhoven University of Technology;
- The Domain of Electrical Engineering at the Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente.

This assessment covers research in the period 2011-2016. In accordance with the Standard Evaluation Protocol 2015-2021 for Research Assessments in the Netherlands (SEP), the Committee's tasks were to assess the quality, relevance to society, and viability of the research programmes on the basis of the information provided by the Faculty and interviews with Faculty management and research Department personnel. Following this, the Committee was to make recommendations for the future.

[1] See Appendix E for the meaning of key wording as used by the Committee in this report

1.2 COMMITTEE COMPOSITION

The members of the Committee were:

Prof.dr.ir. Patrick Dewilde, Committee Chair, Emeritus Director of the TUM Institute for Advanced Study.
Prof.dr.ir. Piet Demeester, Professor of Communication Networks, Ghent University-imec, Belgium.
Prof.dr.ir. Rik De Doncker, Director of Institute for Power Electronics and Electrical Drives (ISEA) and the E.ON Energy Research Center, RWTH Aachen University, Germany.
Prof.dr.ir. Heikki Koivo, Emeritus Professor of the Department of Electrical Engineering and Automation, Aalto University, Finland.
Prof.dr.ir. Robert (Bob) Puers, Professor of Microelectronics and Sensors, KU Leuven, Belgium.
Prof.dr.ir. Dominique Schreurs, Professor of Microwave Engineering, KU Leuven, Belgium.
Dr. ir. Leo Warmerdam, patent strategist at NXP Semiconductors, the Netherlands.

A short curriculum vitae of each Committee member is included in Appendix A.

Ir. Sven Laudy of Quicken Management Consultants was appointed process consultant to the Committee.

1.3 IMPARTIALITY

All Committee members signed a statement of impartiality and confidentiality to ensure they would assess the quality of the research programmes in an impartial and independent way. Committee members reported any existing personal or working relationships between Committee members and members of the programmes under review before the interviews took place. The Committee discussed these relationships at its first meeting. The Committee concluded that there existed no unacceptable relations or dependencies that could lead to bias in the assessment.

1.4 DATA PROVIDED TO THE COMMITTEE

The Committee received the following detailed documentation:

- Self-evaluation reports of the units under review, including all the information required by the Standard Evaluation Protocol (SEP), with appendices,
- “Postcards” and “scrapbooks” with information about staff involved and research topics of each research programme,
- Previous assessment reports 2005-2010.

The Self-evaluation reports together with the interviews and additional information requested during the site visits were the Committee’s key bases for assessment.

1.5 COMMITTEE PROCEDURES

The Committee followed the agenda set by the 2015-2021 Standard Evaluation Protocol (SEP) and modified by the Terms of Reference set by the Committee's commissioning authority, the joint Technical Universities of the Netherlands, represented by Prof. ir. Karel Luyben, Chairman. Contrary to the SEP guidelines, the Committee was asked not to assign each research unit nor the overall Domains to a particular category (1, 2, 3 or 4). This in accordance to the SEP exception rules (p. 4), which allows the Committee to deviate from the SEP.

Consequently, the assessment will be qualitative and its recommendations advisory. As part of this qualitative assessment, the Committee is allowed to make remarks about specific subdomains (called research groups in this report) in the field of Electrical Engineering wherever necessary to establish a global picture on the performance and the prospects of each Domain. However, the Committee was not asked to provide a specific assessment at the level of these subdomains. *Research groups* cover a specific disciplinary area in Electrical Engineering that often correspond to a specific society in the IEEE (Institute of Electrical and Electronic Engineers), the worldwide association in EE, which publishes many major scientific journals and organises many top-notch conferences in EE.

Prior to the Committee meeting and on the basis of their specific expertise, two Committee members were appointed main assessors for the programme of each research group and were asked to lead the evaluation of that particular programme. All members of the Committee were asked by email to make an independent preliminary assessment of the performance of the three Domains on the items required by the SEP. The final assessments are based on the documentation provided by the Faculty, the preliminary assessments and the interviews performed during the visit at each location. The Committee interviewed the Rectores Magnifici, the Faculty Management Teams, and staff of the Graduate Schools and research programmes. Interviews took place on December 6 to 8, 2017 at the Faculties in Eindhoven, Delft and Enschede respectively. The interview schedule with (research) staff and research groups appears in Appendix B. The abbreviations of the research groups can be found in Appendix C.

The day before the interviews, the secretary of the Committee briefed the Committee on the Standard Evaluation Protocol (SEP) for research assessments. This briefing also covered the SEP criteria (Appendix D). It was explained that the criteria *quality* and *relevance to society* aim at assessing past activities, while *viability* is assessed in a forward-looking manner. At that same meeting, the Committee discussed the preliminary assessments. For each programme interview, the Committee prepared a number of comments and questions. The Committee also agreed on procedural issues and aspects of the assessment. All Committee members were actively involved in the interviews. After each interview, the Committee discussed comments and possibilities for improvement. The Committee also offered a separate advice to the Executive Boards of the Universities regarding the current status and general outlook of the field of Electrical Engineering in the Netherlands, whether the combined research activities of the three TU's cover the needs of industry and society adequately nationally and internationally, and the scientific and technological positioning of the three Domains.

Following the on-site visits, the Committee finalised the report through email. Following approval by all Committee members, the Faculty received a copy of the first version with the invitation to correct factual errors. In response, the Committee discussed these comments, made several modifications to the text and then presented the final report to the Boards of the Universities. This was printed after formal acceptance.

See Appendix E for the meaning of key definitions and wordings used throughout this report.

2. General remarks concerning Electrical Engineering Research in the Netherlands

2.1 Research area, objectives and organisation of the research

The three Dutch technical universities cover the Domain of Electrical Engineering (EE) very adequately together, generally at a top international level, with highly competent research groups (between 9 to 15 at each location), a few institutes dedicated to specific areas of technology of excellent calibre, multiple well equipped laboratories, many of which also have a high international reputation, and various collaborative entities such as centres or departments (the mode of organisation of these entities differing from location to location). This is the result of an intense effort at quality improvement and the hiring of staff at a high scientific level over the years, as well as the influence of a technologically advanced industry in the Netherlands and Benelux. The Committee took note of the fact that there has been a substantial shift in the mode of financing of the three domains due to the reduction of first money stream research funding at the onset of the evaluation period, necessitating a stronger emphasis on 2nd and 3rd money streams and hence stronger cooperation with industry partners.

As far as research is concerned, the objectives of the three Domains of EE are sensibly the same: to engage in international top-level research in EE that serves society and solves many technological challenges in society's present day development, to educate doctoral students in the art of technological research and the ability to produce valuable scientific results, to provide a basis for modern education in EE and to function as a centre of expertise for societal use. The Committee has established without any reservations, that the three Domains have achieved these objectives in an excellent way during the evaluation period (with local variations in scope), and should be expected to continue their excellent, domain specific, contributions to the quality of Dutch society in the future.

Over the period of assessment, the three Domains have seen the need to adapt their organisation to changing circumstances, both for internal reasons (evaluations and adaption thereon) and external ones (changes in the funding environment, technological changes, changes in the industrial environment). Some of the salient features are:

- The collaboration between the three Domains in the context of the 4TU association has intensified. This has been a natural process and from the outside the Committee sees the three Domains growing to a more collaborative way of working. The research accents have become substantially different at the three locations, as is evidenced by the development of their Institutes and laboratories. The collaboration has succeeded in letting this happen adaptively. Indeed, it is not a good idea to freeze the past in the organisation by strong mutual agreements. Rather, the leadership of the three domains should be attuned to new opportunities, changing technologies and changing societal demands, utilizing their potential and developing new potential as much as possible. The Committee holds the opinion that the three Domains are doing this very well.
- The transition to a *matrix organisation*, necessary to engage in multi-disciplinary and cooperative research is gradually taking place, with strong local differences. The Committee voices comments on this in the sections on the individual Domains. The Domains can definitely learn from each other's experience (and best-practices at other top-level research institutions).
- The funding situation of all three Domains, their Institutes and laboratories are a matter of serious concern. All three Domains have learned to live with scarcity in the first money stream, by increasing their efforts in the 2nd and 3rd money streams, but these are also under pressure. In the 3rd money stream, the *Fonds voor Economische Structuurversterking* (FES) financing programmes have disappeared. The competition at the EU-level has intensified to often irresponsible levels (less than 10% general success in project applications is irresponsible: a waste of time and energy for the applicants and an awarding process that looks more like a lottery than an honest brokerage). The only remaining major source of income for research is then contract research with industry. The Committee has observed that the Domains have adapted well to the situation, but that should not reduce the level of concern. A healthy development of the three

Domains requires adequate 1st stream funding. A too high dependence on just contract research may be at the expense of very necessary fundamental long-term research, since much contract research is applied research by definition and has an inherent danger of short sightedness. The need for long-term research has been amply demonstrated by the trend in modern technology to utilize ever deeper fundamental scientific principles and methods, as evidenced in ever more complex systems, e.g., in telecommunication, micro-electronics, robotics, the transition to renewable energy and smart grids.

All this amounts to a very positive assessment of the overall situation concerning coverage, objectives and organisation of the EE research in the Netherlands. Nonetheless, the Committee has observed a number of points that may need improvement, to be detailed next, followed by a number of recommendations.

OPPORTUNITIES FOR IMPROVEMENT

- Although the self-assessment reports cover the research areas presently active in EE well, they do not offer an adequate view on the future technological and research challenges these areas pose. Many individual research groups do provide ideas on these, as demonstrated in the individual research group interviews, and provide even roadmaps to handle them (as is often done in micro-electronics), but a present-day consolidation at the Domain level is lacking, including consequences derived from them for further development of the choice of research topics, the filling of staff positions and the development or even creation of new facilities.
- On benchmarking, the Committee finds the benchmark of RWTH at Aachen inconclusive and incomplete. Aside of identifying structural similarities, such as the research Domains and the research matrix structure of faculties and interfaculty centres, no best practices on the scientific or technological choices between the respective Dutch Domains and the corresponding Domains at RWTH are addressed in detail. Governance is very different in Germany from the Netherlands with different effects concerning student-to-staff ratios, curricula, status and ratio of junior-to-senior staff and

funding situation. A detailed analysis of these consequences helps to assess best-practices of the respective approaches. This was done to some extent for the area Sustainable Energy as an example. From the high level analysis, it appears that the Dutch Domains are following a strategy that is very much in line with what happens at RWTH, mostly out of necessity. With dwindling income from the first money stream, bundling research offers new opportunities for fundamental research. Institutes can better cooperate with industrial partners in the third money stream and consortia linked to Centres can provide better access to R&D funds both in the second and the third money stream. A conclusion of the visit was therefore that good fundamental research does not have to suffer from cooperation with industry.

- The three Domains agree on primary societal challenges their research should address, roughly characterized as *digital society*, *health*, *sustainable energy* and *advanced materials*. Each of these topics presents a large collection of potential research challenges. The choices each Domain makes adaptively, based on its potential, its history and its individual strategy for the future, would benefit from regular and mutually reinforcing coordination, aiming at increasing the common knowledge base, complementary use, as well as further developments of facilities and expertise. The Committee has observed that the choice for these core societal challenges is not always well known at the level of the research groups. A dialogue on strategy between the research groups planning their future and the leadership of the respective Domains seems therefore highly desirable.
- As far as micro-electronic technology is concerned, the choice for *More than Moore* is obvious, and shared, in different ways and with different emphasis, by the three locations. This very wide area is on the one hand well suited for a multidisciplinary approach, but, on the other hand, in need of clear focussing, given its many fields of application (medical, automotive, robotics, sensing and actuating, energy conversion etc…) and the many techniques that can be used.

RECOMMENDATIONS

- Formulate your main research questions and technological challenges by consolidating the views and roadmaps of your research groups, Institutes and Centres at the Domain level. Both for yourself and for the outside world, make your collaborative multidisciplinary research choices visible on the internet together with a chart of the main competences you have and how you want to develop them further in a coordinated way at the Domain level. Such actions will increase your visibility and attractiveness to potential students and industrial parties. Update the views in regular intervals (e.g., every six months) in a body of the Faculty where the scientific strategy is being discussed.
- Since the most important issue is the scientific/technological strategy for the future of the respective Domains, a benchmark study of the research questions and the technological development envisaged at the most prominent institutions in Electrical Engineering (MIT, UCB, Carnegie-Mellon, Cambridge University, KU Leuven, RWTH, TUM, Imperial College, DTU, KTH etc...) should be mandatory. All the institutions are of course entitled to develop their own research strategy, but it certainly helps very much to know and assess what the prominent other institutions are up to. (Such an effort would be useful for all parties concerned.).
- Strengthen the efforts for regular coordinated actions on how to deal with the main societal issues for the common area of Electrical Engineering as far as education, research and development of facilities are concerned, based on a possibly region-specific need for knowledge and expertise in society (an in-depth study of the *needs for knowledge* should form the basis of such an assessment.).

2.2 RESEARCH QUALITY

The overall quality of Dutch research in Electrical Engineering is impressive. Each of the locations has a good number of internationally renowned top scientists as testified by the number of IEEE Fellows, the number of both national and international awards obtained during the evaluation period, a good number of high *h-index* scientists and a number of great scientific and technological contributions, all to be discussed further in this report in the Domain-specific sections.

The total scientific output at the three domains can be evaluated as *very good* to *excellent* (according to the SEP terminology: *excellent* for *internationally recognized as top level*, *very good* as *internationally recognized*, *good* as of *good value* and then *satisfactory*, as testified by the average number of publications per awarded PhD-thesis, the output in research papers per permanent staff member and the average/median h-index, see also Tables 1 and 2).

	TUD	**TU/e**	**UT**
Average h-index	20.96	16.96	20.98
Median	15.00	11.00	15.00

Table 1 Average and median h-index of TUD, TU/e and UT, based on numbers provided in the self-assessment reports

	Total peer reviewed journal papers	Total conference papers	Awarded PhD	Total Scientific Staff research FTE	Total staff member research FTE (1)	**Total peer reviewed papers / Total Awarded PhD**	**Total peer reviewed papers / Total research FTE scientific --**	**Total peer reviewed papers / total research FTE staff member**	**Total conference papers/ total research FTE staff member**
TUD	1180	2088	212	123.1	321.9	**5.6**	**9.6**	**3.7**	**6.5**
TU/e	1431	2596	215	185.3	349	**6.7**	**7.7**	**4.1**	**7.4**
UT	1010	1267	213	116.7	312.3	**4.7**	**8.7**	**3.2**	**4.1**

Table 2 Various 'metrics', measuring weighed output numbers for TUD, TU/e and UT. Totals in the period 2011-2016 **.** (1)Total research staff member FTE is total FTE of (scientific staff + postdocs) spent on research

The Committee has struggled with the interpretation of the data provided by the three Domains. In particular, the count of *staff members* engaged in research (essential in the assessment of the overall scientific performance) has been problematic, because of the very different constitution of research staff at the three locations (number of full time permanent research staff, part time staff, staff supported by industry and postdocs). Table 2 shows data assembled from the self-assessments of the three Domains and interpreted according to a few metrics. The table shows minor differences between the three Domains, and potential areas of improvement, even though the data shows on the whole *very good to excellent* performance at all three locations. Differences of several points in the averages are insignificant because (1) counting number of publications does not reflect their quality and (2) the way of counting contributing staff members is different at the three locations. More refined metrics could be devised but would very likely not lead to different conclusions: the Committee has the impression that the overall scientific output of the three Domains is significant both in numbers and in quality. A comparison with the normalized output of some other major institutions in the self-assessment reports would have been helpful to make the assessment stronger. The Committee recommends such an action for the next assessment effort.

2.3 Relevance to Society

There are (at least) two aspects to *relevance to society*: whether the topics covered are indeed relevant, and whether the research groups/ Institutes/ Centres/ Domains take necessary actions to make their research relevant to their surroundings. These two sides may sometimes appear to contradict each other, especially in the engineering field. That is the case when advanced research is not addressing topics of immediate needs of (local) industry. Such advanced topics can be very necessary for the development of main areas of engineering and long-term societal challenges, not limited to the local environment. There are many examples of this phenomenon, and of topics that suddenly became highly relevant after having been relegated to *arcane science of no use* (e.g., graph theory, prime numbers, quantum dots, nano-layers, deep-UV, super-conductivity). The Dutch authorities (in contrast to American authorities) mostly ask for direct industrial relevance when deciding on support of technological research. This is a reality the Dutch technical universities have to cope with.

Aspects and levels of relevance are often described by a *Technology Readiness Level (TRL).* For the definition of the Technology Readiness Level's we refer to Table 3. These levels have to be interpreted with care and with reference to the specific field concerned. It may happen that a new insight produced at TRL 1 has direct industrial relevance (think e.g., of CDMA in telecommunication or CRISP in genetics). Conversely, it happens that research at TRL 5 leads to fundamentally new methods at TRL 1 (e.g., electronics developed for the LHC in Geneva or for deep space astronomy), and then finds applications in unrelated domains.

Technology Readiness Level	**Description**
TRL 1.	basic principles observed
TRL 2.	technology concept formulated
TRL 3.	experimental proof of concept
TRL 4.	technology validated in lab
TRL 5.	technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 6.	technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
TRL 7.	system prototype demonstration in operational environment
TRL 8.	system complete and qualified
TRL 9.	actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Table 3 Example of Technology Readiness Levels, as used in the European Commission

The Domains deal with this situation by following a careful course, whereby the fundamental, disciplinary research is mostly handled by the research groups and is fuelling the educational curriculum, especially at the master's level. This is called TRL 1-2 research, although major research institutes also engage in such topics in order to improve on their technological expertise (e.g., fundamental activities in materials research). The more industrial relevant part of the research (TRL 3-6) can be very innovative as well, and typically occupies about half of the research efforts of the research groups and a large portion of the research in the Institutes and Centres (those being collaborations between research groups aiming, in particular, at attracting industrial research contracts). Some groups go more for fundaments and others for direct applications. The source of funding (1st, 2nd and 3rd money stream) gives a rough indication of the TRL level of the supported research and the proportions vary between the three Domains. The overall balance between lower and higher TRL levels measured in this way appears to be roughly

50/50, which the Committee considers healthy, although the data shows a marked tendency towards increasing the higher TRL levels. This may, in the long run, substantially diminish the volume of fundamental research, which in EE has been a major source of innovation in the past, partially explaining the successes of recent American companies in EE like Google, Apple, Cisco or Qualcomm.

On the side of making research results useful for society, the Domains engage in contract research with industry, in facilitating the creation of spin-offs and in defining research topics that will produce PhDs with exceptionally useful competences. The results obtained by the Domains in these endeavours are varied (and are detailed further in the individual Domain sections).

RECOMMENDATIONS

- The Committee advises the Domains to investigate the *demand for knowledge and expertise* from Dutch and European society (companies) to a good level of detail (along the lines of our advice to chart future research challenges), so that a clearer picture emerges of which competences the research groups should cater for and which new competences should be developed. So far this has been an adaptive process, mostly geared through joint research projects and contract research with industry. While this is a good method, the results could be consolidated in a more comprehensive picture that would complement the default bottom-up approach. This would, when well documented, increase the attractiveness of the university research. Such efforts have been initiated at the three locations by the creation of *themes*, but these have been driven more by current trends than by *demand for knowledge and expertise*. An inventory and motivation for the latter would be a good task for the embryonic Themes.
- Many, if not most, industries have dismantled their research environment to a large extent. The Domains, their research groups and Institutes are engaged in efforts to fill the gap. Such efforts could be strengthened and lead to major contracts with powerful industrial partners (there are already some good examples in the Domains visited.) This would also be an eminently useful task for cooperative endeavours like Centres or

Departments to engage in. There are already good examples on how to go about the setting up of collaborative basic research supported by a sector of industry, which then profits in direct line from the results (see also the model used by imec or the Holst Institute).

- The creation of spin-offs could be further facilitated, e.g., by allowing a more fluid transition from research to entrepreneurship via *resident entrepreneurial researchers* and other measures that allow utilization of resources for spinning-off innovations from the university laboratories.
- The Committee would like to see a better documentation of the industrial valorisation performance. The Committee advises the responsible authorities to ask for a uniform view (over the three Domains) on the industrial valorisation performance (income from public authorities like the EU, income from licences, pure bilateral income, spin-off companies, …) in future reports. The same goes for a uniform way to provide data concerning funding, staff and research output, as mentioned above, and in addition including a clear distinction between start-up (no IP transfer) versus spin-off (IP transfer).

2.4 VIABILITY

Thanks to the general strong increase in first year students at all three locations and a systematic increase of third money stream income, the financial situation at the three locations has become manageable. Nonetheless, given the very fast technical development of the field in many new directions and the great societal demand for knowledge and expertise in Electrical Engineering in most technical areas, from medicine to mobility and energy, the challenges on the further development of the Domains themselves are serious and will need a major and continuous effort to at least sustain the present outlay, to engage in new initiatives and to provide for sufficient funding.

The field of electrical engineering offers many new opportunities for advanced research as well as innovative applications in general, and in particular in the areas the Domains have selected as their main emphasis. These are still formulated in a very general way in the sections on future perspectives. Each Domain has clearly to focus further within these broad areas so as to achieve scientific and technological results that can compete with the best efforts worldwide.

The Committee has observed that the scientific output is under pressure due to the increased educational load of the research staff, as a consequence of the strong increase of the number of students at the three locations, which has to be matched by a sufficient increase of permanent staff, just to maintain the present productivity (which is high). In addition, the ratio of junior professors to senior professors (young assistant professors vs. associate and full professors) is generally too low and should be increased to over 60% (so-called *rejuvenation*) to meet the most desirable level. Junior professors are very important because of their dynamism, both in the sense of engaging into novel domains of research and in the production of research and technological output. To achieve this, a consistent *tenure track* programme is necessary. The three Domains have such programmes, but a stronger effort will be necessary to reach the 60% ratio of junior-to-senior staff. It will remain crucially important that the three Domains hiring policies aim at appointing scientific personnel of recognized top international standing.

The research at the three locations is supported by very valuable, effective and important facilities, which deserve not only extensive continuous support from the Dutch society, but also must engage in new directions as technology changes. In view of the almost systematic dismantling of industrial research facilities by the main companies in, for example, microelectronics, the research facilities at the technical universities have acquired a much higher importance as a site of knowledge and technical expertise for the Dutch and the European society than before. Compared to e.g., Germany with its *Excellence Initiative* and certainly the USA, the Dutch technical universities are relatively starved of developmental funds, a situation that can only be detrimental for the knowledge position of the Netherlands in the future. Nonetheless, it can be stated that the three Domains under assessment have made very judicious and complementary choices on how and which technological facilities to develop (e.g., Photonics in Eindhoven, Quantum Electronics in Delft and Nano-technology in Twente among many other, less massive but equally important facilities). These efforts have led and are leading to world-class facilities at the three locations. Further information on this can be found in the sections on the individual Domains.

The three Domains in the Netherlands have developed a productive model of cooperation. The Domains have realized that cooperation is necessary to produce a basis on which their research groups can share knowledge and facilities on one hand, and compete scientifically on the other hand, in order to produce the best possible results. Modern technologies are very demanding quality wise, due to the strong international competition and the rapid development of the field. Modern technologies are also highly multidisciplinary (not limited to electrical engineering, and in particular using expertise from physics, chemistry, mechanical engineering and recently biology, medicine and computer science and hence requiring knowledge input from many sources). The three Domains under review have recognized this situation and have created various collaborations to address the need for a broad and qualitatively excellent knowledge base.

Research at the three Domains is gradually getting highly dependent on funding from the third money stream (in some cases more than half of the income originates from it). While this situation may be applauded by public authorities and alleviate their financial burden, the situation is not without danger for the overall quality of the Dutch knowledge position. An auxiliary and connected issue is that much of the research is performed by young scientists with short term appointments (PhD-candidates and postdocs), making it a point of attention to capture the acquired knowledge in the Domains for the longer term and for educational use.

RECOMMENDATIONS

- Central elements and motivating factors to guide the continuous development of each Domain are (1) the scientific challenges and questions the Domain and its research units want to address, (2) the need for knowledge and expertise in the chosen societal areas, (3) the international development of the technology necessary for the chosen areas of research. The Domains should set up actions to chart these factors regularly and in cooperation, and then derive policy consequences from the acquired insights, thus influencing the research unit roadmaps top-down with their big picture in mind.

- In particular, the appointment policy of new staff members (e.g., tenure track appointments but also the renewal of technical staff) has to take the conclusions of the exploration described in the previous bullet into account, with the explicit aim at strengthening the respective knowledge positions. These efforts should also lead to eventual modernisations of the educational programmes offered.
- The strategy, governance and funding of research facilities at the three Domains is unclear. The Domains should set up a concerted effort to assure the future development and financing of their facilities, given the possibilities of the Dutch system. This will require continuous effort and leadership from all senior researchers and their supporting faculties.

2.5 PhD PROGRAMMES AND GRADUATE SCHOOL

The three Domains have adequate programmes to support the needs of their PhD students. In particular, all three offer courses in *soft skills*, most notably writing, language and leadership skills. The PhD-candidates are mostly very satisfied with these (with some local variations, see the comments for the specific Domains).

The three Domains fail in having more than 60% of their PhD-candidates produce their thesis within a period of five years. The Domains offer various excuses for this situation (including an explanation for the sometimes not negligible number of *dropouts* often due to early employment offers in industry), but a thorough study of the causes of the low rate of success in this area is lacking at all three locations.

RECOMMENDATIONS

- The leadership of the Domains should take much more stringent measures to control timely defence of PhD thesis of their candidates. The Committee recommends the early control on the quantity and quality of written material taken more seriously than at present, as well as the obligatory presentation of a concept thesis within two years of research, and a more consolidated version within three years;

- Also, the Committee recommends that a better analysis be done by the three Domains (it is not one size fits all) of the reasons for dropout (meaning the candidate unilaterally terminates his contract without reaching a PhD) and for extensions beyond four years. Appropriate measures then have to be taken on the basis of the findings. (As the PhD period is to be considered a learning phase, it is not advisable to extend it beyond four years. PhDs have to move on into society after their doctoral period, for their own benefit, but also for society's benefit.)

2.6 INTEGRITY

The 3 TU's have adequate integrity policies on matters such as honesty of research results and handling of data obtained from their research efforts.

On other topics, such as the propriety of specific research results originating from contracts as well as the rights and duties of staff members and PhD-candidates working on such contracts, no information is given (although most groups seem to have informal policies in these matters).

Also, a clear policy is not explicitly mentioned, in all three Domains, on the authorship of publications (who should be an author and who should not be an author).

Recommendations are given to all three sites to complement their Research Integrity Policy with a formal policy on the matters mentioned.

2.7 DIVERSITY

The diversity issue is also multi-variable, with several components:

- The international constitution of the permanent and junior staff;
- The constitution of the student population in the three categories (BSc, MSc and PhD), as well as the transition flow between them;
- The ratio of female-to-male members in the different categories.

The situation concerning the international constitution of the permanent staff seems very different in the three Domains, with EE at Delft being by far the most international. The ratios female-to-male are everywhere much too low, especially in the permanent staff. The Committee makes individual recommendations for each Domain on these matters, but they can be summarized as follows.

RECOMMENDATIONS

- The international community of recently graduated, top level PhDs is large and can be exploited much better for junior permanent staff positions (assistant professor level). In general, there is an excellent supply of top scientists internationally in all categories, including women. To capitalize on this pool of talent, the Domains should (1) offer attractive conditions both in terms of local embedding and remuneration, (2) assist in the transition to the Netherlands much better than they are doing at present, (3) exploit the international contacts and resources of the top research groups to scout for excellent new staff members, and (4) offer a starting package for a junior professor: now they are not supported in a structural way, this could be improved (e.g., offer them funding for 2 PhD students and a Post Doc for 5 years);
- The ratio of female-to-male staff should be increased systematically, by affirmative action and by setting targets for new appointments. International hiring is an absolute necessity for this, in view of the small influx of female Electrical Engineers of Dutch origin. (Some Domains already have a strong affirmative action in place, but more should be done.);
- The attractiveness of the university environment for women should be enhanced. In particular by providing better working conditions. Best advice for adequate measures may be provided by your female staff.

2.8 FACULTY'S EXTRA QUESTIONS

The Executive Boards of the universities also asked the Committee to reflect on the following topics:

- The current status and general outlook of the field of electrical engineering in the Netherlands;
- Do the present and combined research activities of the three TU's in the field of EE in a broad sense, sufficiently cover the needs of industry and society both nationally and internationally?
- What are the Committee's comments and advice on the way in which the universities position themselves in the face of upcoming challenges in the area of electrical engineering and in mobilizing the support from government and industry?

The current status and general outlook of the field of electrical engineering in the Netherlands

This very valid question is in need of a professional investigation, which the (international) Committee cannot provide since it would require a profound screening of the Dutch industry. Partial answers can be provided by the many contacts researchers at the three Domains have with industry. Nonetheless, some immediate observations gleaned from experience with the field and what has transpired from contacts with the research groups during the visitation can be given.

The societal motivation given by the three Domains for their research is very genuine and well-tuned to societal needs. Knowledge of Electrical Engineering and access to progress in the many complex issues EE research is dealing with, is essential in many areas of industrial development, for example,

- Increasing the intelligence and functionality of systems (integrated sensors, data handling, control, system integration, actuators) is needed for the automotive industry, professional apparatus, mobility, smart infrastructures;
- Providing new types of electronic devices is needed in almost all products of the manufacturing industry and in particular in the manufacturing of medical equipment and sustainable energy production systems (sensors, actuators, signal processing, control, networking, communication, system design);

- Quick and reliable access to information as well as security in the vastly expanding digital world is a primary need of our present society;
- To ensure sustainability, essential contributions from EE are needed. Power generation has to become sustainable, and this is a direct competence of EE; think of PV, Smart Grid, power electronic devices, in particular for low-, medium- and high-voltage DC power generation and transmission, Also sustainable industrial processing, automation and emission-free mobility are highly dependent on solutions from EE.

In all these areas, there is considerable industrial activity in the Netherlands, and many of the companies have, sometimes intense, contacts with the three EE Domains. These companies and their development, as well as the areas they stand for, do not only depend on a sufficient supply of excellently educated engineers, but, and in an increasing fashion, on their access to new technologies and their ability to introduce it in novel or customized products. The international competition is fierce in the open world market, and success depends increasingly on the right technological solution. This has well been demonstrated by the demise of the European industry in consumer electronics and in communications in favour of American and Korean companies, who were offering much more advanced products for reasonable prices (e.g., the iPod or the iPhone, but also the internet and WiFi technology). Europe and the Netherlands are capable of designing and producing top of the line products and are able to create companies with a large market share, provided they succeed in bringing the best expertise in their products (e.g., ASML, NXP, Thales, Royal Philips, FEI and there are many more examples in less visible sectors of industry.)

The outlook for EE education at the three Domains has considerably brightened since the 300% higher intake of students at the BSc level. However, the financial basis of university education in technology (including EE) remains shaky: the intake of every student at the BSc level actually costs the Domain a substantial amount that is not covered by 1st money stream (around 8000 Euros per student). This situation takes financial resources away from research, or, to put it differently, research income is effectively used to subsidise basic education. This is not a healthy situation and should be remedied, which would happen when public authorities would increase the allowances per engineering student in the first money stream, given the fact that knowledge and expertise in engineering requires advanced experimental facilities and hence does not come cheaply.

The Domains have made changes in strategy and organisation after government cuts in direct funding and have recovered quite well thanks to re-organisation and a substantial increase in contract research. In the future, the EE research will require more and more interdisciplinary cooperation. Given their experience, the status and outlook for the three Domains look very good. The EE Domains have world-class research and their overall coverage is seen to be adequate. Their level of competence is excellent. Nonetheless, visibility could be improved, e.g., by documenting the research ambitions on the internet and providing information on *where to find what* in knowledge-country Netherlands (or even Benelux).

Generally missing to properly charter the future of the Domains are:

- An analysis of the needs for future knowledge and research at all three places;
- The process of development of new areas and new professorships;
- A clear idea on action to be taken for future financing of facilities;
- How the analysis of societal needs translates into developmental actions.

Do the present and combined research activities of the three TU's in the field of EE in a broad sense, sufficiently cover the needs of industry and society both nationally and internationally?

The Committee is somewhat surprised to see this question directed to itself. The Committee had expected to read information on this in the self-assessment reports. The same goes for the next question. Nonetheless, the Committee will try to give some feedback on this issue.

System of Systems (Industry 4.0, other names are also used) should be studied more in the future. In some themes of the Domains, System of Systems is included, but the area is very large and rife with issues. Possible other themes to consider: hospital systems, railway systems including stations and people, intelligent city traffic including both smart cars and cars with drivers, smart city. The list is very long in this area and requires cooperation. It will involve close cooperation between relevant technology, design and system engineering groups, as the solutions will depend on a close interaction between all these. Such mutual understanding from diverse areas has proven very difficult in the past, and will require people who can transcend their own specialty and idiosyncrasies.

There seems to be a good distribution of interests among the three Faculties, in the sense that what is missing in one can often be found in another. It would be good to set up a comparison with the main IEEE societies and how they are represented in the Netherlands (some may not be relevant, but others may be missing). Such a study should not be difficult.

Although the three TU's profess *multi-disciplinarity*, more could be done, in particular facilitating joint PhDs with other fields (mechanical engineering, biology, bio-medical). The Committee encourages to expand on the idea of allowing professors in medicine to supervise doctoral candidates in EE and vice-versa. (This is a direction Stanford University is taking, forcing an advising professor to study an unknown discipline. One Committee member was attending a conference in which two of the most important innovators in California were telling of the fact that when they started they had to learn everything from scratch and ended up with solutions that were much better than the standard industrial solutions. Their implementation (e.g., in Qualcomm, Intel or Apple) killed the corresponding European industry.)

The development of facilities at the three places (in a concerted effort) requires more attention, in particular as how to finance them. Finding adequate financing is dependent on the definition of a convincing and ambitious research programme and requires the formulation of clear and relevant research questions. This is an exercise only the top people in the given field can do, and, luckily, the Domains have such people as members.

The Committee thinks the *benchmarking with RWTH* is a first step, but the report remains insufficient and superficial, in particular where it concerns the definition of research questions and the development of research areas. In addition to RWTH, the 3 TU's should engage in an in-depth study of scientific development at a number of other major institutions, say e.g., MIT, Stanford, Cambridge and a few more, including such institutions as imec. Such benchmarking should be a standard component of future self-assessments.

To solve problems of society, one has to understand society (culture, economics, etc). This can be done by clarifying the position of EE as an essential, enabling technology for society. It should not be hard to document *how* EE changes society and can solve some of its problems.

What are the Committee's comments and advice on the way in which the universities position themselves in the face of upcoming challenges in the area of electrical engineering and in mobilizing the support from government and industry?

The societal aspects of the research could be expanded and documented further. Some current needs of industry (knowledge, technology) are well covered by the Domains, at least nationally, but an estimate of future needs per area or theme should be made, including a clarification of how the insights in societal needs will influence the development of the Faculties (new chairs, institutes, technologies, collaborations and curricula). Well-documented insights in estimated future needs of the Dutch industry would be helpful to mobilise their support and that of the Dutch government.

It would also be useful to indicate what needs are covered by the 3 TU's, versus imec, TNO, Holst, QuTech, and possibly the big NWO (Nederlandse Organisatie voor Wetenschappelijk Onderzoek) institutes. You might consider creating separate institutes or centres especially devoted to provide societal expertise, e.g., in areas of sensing interfaces, medical devices, sustainable energy or security, i.e. *knowledge shops* for policy makers.

Organisational changes made during the period 2014-2016 have improved the overall situation of the Domains, but need regular evaluation of the benefits of the existing structure and improvements that can be made. The Domains can learn from each other, and there is good evidence that they do. There is some overlap in the research at the three locations, but each Domain has top areas not covered by the others.

3. ASSESSMENTS OF THE DOMAINS OF ELECTRICAL ENGINEERING AT TUD, TU/E AND UT

The Committee assessed the research at:

- The Domain of Electrical Engineering at the Faculty of Electrical Engineering, Mathematics and Computer Science, Delft University of Technology;
- The Faculty of Electrical Engineering, Eindhoven University of Technology;
- The Domain of Electrical Engineering at the Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente.

The assessment of each Domain is presented in this section. The remarks and recommendations of the Committee are to a large extent dependent on the information that has been provided in the self-assessments and during the visits. This may explain some differences in the treatment of the individual Domains, although there is a general similarity between the three concerning such issues as support for PhD-candidates, research integrity and diversity. Some repetition of recommendations is therefore unavoidable.

3.1 RESEARCH AT THE DOMAIN OF ELECTRICAL ENGINEERING AT THE FACULTY OF ELECTRICAL ENGINEERING, MATHEMATICS AND COMPUTER SCIENCE, DELFT UNIVERSITY OF TECHNOLOGY

Faculty Dean	Dr. John Schmitz
Research staff 2016	60.7 Research FTE (excluding PhD)

As mentioned in the self-assessment report, the *Domain of Electrical Engineering at the Faculty of Electrical Engineering, Mathematics and Computer Science at TUD* (further to be called EE) believes in a technology-driven approach to fulfil societal needs in a global context. The Domain states that in a digitized world, all challenges are by definition multi- and interdisciplinary. That is why EE aims at solutions that are system integrated, combining game-changing technologies with state-of-the-art EE expertise.

The strategy for EE research at TUD for 2011-2016 focused on what it calls three major transitions: the digital transition, the health transition, and the energy transition. Based on developments in these areas, specific research topics have been selected as time progresses.

Taking into account the Committee's evaluation at the mid-term assessment (2015) regarding a missing overarching framework for the units and themes, EE has developed a new concept called *research themes*. These research themes are clustered in three major groups: major societal challenges, innovation opportunities, and enablers. The major societal challenges consist of overarching problems in society that the research units want to solve by looking at innovation opportunities. By addressing these innovation opportunities, EE aims at creating the in-depth academic knowledge needed to solve the societal challenges. In order to facilitate the research into these innovation opportunities, EE has defined enablers that should help to establish a strong and flexible research organisation.

The research outlay was composed in 2016 of 22.5 FTE scientific staff, 38.2 FTE post-docs and 143.1 FTE PhD-candidates.

Table 4 shows the documented research output of the EE-part of the Faculty in the assessment period.

	2011	2012	2013	2014	2015	2016
Refereed articles	173	206	189	198	216	198
Non-refereed articles	2	7	6	1	4	4
Books	4	1	4	5	1	5
Book chapters	24	20	15	21	6	9
PhD theses	50	31	34	42	15	40
Conference papers	517	381	302	325	328	235
Professional publications	5	2	1	3	5	0
TOTAL	**775**	**648**	**551**	**595**	**575**	**491**

Table 4: Total output of EE at the Faculty of EEMCS

The composition of the research staff at EE within EEMSC is found in Table 5.

	2011		2012		2013		2014		2015		2016	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff	72	24.5	61	21.2	54	18.1	55	18.4	56	18.4	70	22.5
Post-docs	46	32.9	47	33.4	43	31.1	46	32.2	45	31.0	56	38.2
PhD-students	192	138.1	173	127.9	167	124.5	178	131.1	183	130.2	202	143.1
Total research staff	**310**	**195.5**	**281**	**182.5**	**264**	**173.7**	**279**	**181.7**	**284**	**179.6**	**328**	**203.8**
Support staff	68	43.8	49	31.4	45	30.7	45	32	45	33.1	50	36.8
Visiting fellows	11	0	10	0	9	0	8	0	7	0	4	0
Total staff	**389**	**239.3**	**340**	**213.9**	**318**	**204.4**	**332**	**213.7**	**336**	**212.7**	**382**	**240.6**

Table 5: Staff embedded in EE

The total funding of EE is found in Table 6.

TOTAL	2011		2012		2013		2014		2015		2016	
	k€	%	k€	%	k€	%	k€	%	k€	%	k€	%
Direct funding[1]	6897	30	6661	32	5824	30	6636	31	7433	37	8609	37
Research funding[2]	3109	14	3073	15	2987	15	3149	15	4051	20	2615	11
Contract research[3]	9496	42	9023	43	8994	46	11010	51	7825	39	10758	46
Other[4]	3337	15	1993	10	1670	9	885	4	848	4	1192	5
Total funding	k€ 22839		k€ 20751		k€ 19476		k€ 21679		k€ 20157		k€ 23173	

Table 6: Total funding at EE. All amounts in k€.

1. Direct funding by the University, obtained directly from the University, and financial compensation for educational efforts.
2. Research funding obtained in national and international scientific competition (e.g., grants from NWO, KNAW, EU/ERC, ESF).
3. Research contracts for specific research projects obtained from external organisations, such as industry, government ministries, the European Commission, and charity organisations.
4. Funds that do not fit the other categories.

RESEARCH AREA, OBJECTIVES AND ORGANISATION OF THE RESEARCH

The organisation of the Faculty in departments and research groups is clear: the Departments form a management layer intermediate between the Board of the Faculty and the research groups. A new Department in quantum and computer engineering has been created in 2016, and it consists of research groups that were previously part of other departments. The new Department has been created to address ambitious research goals in the direction quantum devices and quantum computing architectures.

The visions of the three Departments on their mission, their goals and their scientific future are largely missing in the report but have been summarily provided during the initial presentation of the site visit. The Committee finds the mode of organisation effective: it largely brings research groups together around a shared area (Electrical Energy, Micro-electronics and Quantum Engineering) and the development of common facilities. Nonetheless, the need the Faculty sees to create *themes* may indicate a need for more flexibility and more cooperation between the Departments.

The general mission and goals of the Departments are clear as well. The choice of societal issues is well taken, but pretty general. The Committee learned during the visits of the research groups that these societal challenges are not recognised by some of these groups. The Management Team is aware of this and realises that not all of them fit into the themes. This is perfectly fine since the overall themes should not be seen as constraints but as opportunities. Perhaps over the years theme awareness will grow. The themes chosen are adequately supported by a number of relevant research groups. In general, the groups are focussing well on important research topics.

The Committee considers the decision to invest in Quantum Engineering as a very strong choice. This gives good opportunities for innovations and industrial cooperation on an international scale and at a top level of expertise, as testified by a recently acquired, extensive contract with Intel.

The development of a major research Department with modern technological facilities in sustainable energy, smart grids and cities is also a very good move. These efforts deserve strong support for the timely retargeting of the High Voltage Laboratory by the Faculty and TUD, including arrangements to increase the influx of students.

Also the Microelectronics Department is developing very valuable new centres of expertise in molecular electronics and bio-electronics, besides providing facilities to create new devices in high frequency electronics. The collaboration of both the Department of Microelectronics and Quantum Engineering with other Faculties inside and outside TUD (e.g., with UT in the area of bio-electronics) as well as with TNO (in the context of QuTech) is productive and hence highly commendable.

The Domain of Electrical Engineering at TUD clearly has a strong international orientation, as testified by a large number of staff members and postdocs from outside the Netherlands and a large intake of international students at the master's level .

Concerning the TRL of the research: the Committee has observed quite a wide range. Some groups work at a very basic TRL, others are active at industrial TRLs. A tendency towards higher TRL can be observed, following a heavier dependence on contract research, although some of the larger contracts do support low TRL research (in particular in Quantum Engineering).

RESEARCH QUALITY

The number of reviewed journal papers has remained roughly constant over the years. On the metrics in Section 2.2 we have noted that they amount to a total production of 6.5 conference papers/total research FTE staff member and an average production of 3.7 reviewed journal papers per total research FTE staff member. This can be considered *very good* (in the SEP terminology) with peaks of excellence.

The number of conference papers has substantially diminished over the years. It has been claimed that this is compensated by an increase in quality as shown by a good number of best-paper awards and by substantial visibility in major conferences and journals. The Committee agrees with this explanation and supports this strategy.

The overall performance as testified by numbers of papers, research contracts, patents, awards and average h-index is very good with peaks of excellence in some groups. EE has a strong funding portfolio and very strong collaboration in major projects. Overall, the amount of personal top grants is very good. EE has received numerous major grants: 5 NWO grants, 6 ERC grants, 32 other grants above 500,000 Euros. 46 best paper awards and numerous other awards, especially from different IEEE Societies. EE shows a good number of spin-off companies (18) and a large number of patents. Also, EE at TUD excels with an impressive number of technical products and proof of concepts used by industry.

The average h-index in 2016 is 21 with median 15, which should be considered very good for an engineering discipline.

Relevance to Society

The report is unclear with respect to the scientific and technological vision (research challenges and questions to be addressed) of the Domain of EE in Delft and how such a vision influences the future development of the Faculty, except for the choice of the creation of the new Department of Quantum Engineering (QE). However, the research groups gave clear insights in their roadmaps and scientific goals during the visit. These need to be consolidated at the department and faculty level.

Overall there are very intensive connections with industry. Connections with society (thus non-commercial valorisation) are not clearly presented in the report. Again, the groups gave better insight to the Committee during the site visit. Here also the large international outlook is obvious.

The newly consolidated fields of sustainable electrical energy generation and transmission, QE and bio-electronics are well covered and of high societal relevance. This applies to most existing fields as well. In view of the substantial third money stream, societal relevance is clearly not a problem, although the research groups and the Domain could investigate the *need for knowledge of EE in society* in more detail, document their findings and derive consequences for their further development.

Viability

Governance

There is an unbalance between the Departments concerning their size. Microelectronics (ME) in particular is covering a very broad collection of topics, ranging from micro-electronic technology over various types of devices and sensors, design technology, signal processing, and even radar and telecommunications.

The Committee formed the impression that the total ratio students (BSc, MSc and PhDs) to staff is generally high, although it is compensated somewhat by the large number of postdocs.

The Committee has the impression that the collaboration and exchange between the Departments could be intensified, although some strong collaborative efforts, e.g., in device technology, do exist. Within the Departments there is generally very strong collaboration between the research groups (see also the remark on the size of ME).

RECOMMENDATION: the Committee recommends a strengthening of the adaptive development of timely relevant themes and concordant intensification of their prospective efforts, as well as an evaluation of the appropriateness of the present departmental structure (benefits vs. disadvantages) in the light of theme development and in addition, also of the Institutes, which are present, but less visibly presented to the Committee.

Future strategy

The Committee has observed a healthy development of the student population at the various levels.

The strategic positioning of the three Departments both scientifically and with respect to societal relevance is very strong. Nonetheless, the Committee wishes to insist on the necessity of focussing and on collaboration with sister laboratories in all three fields, so as to increase the knowledge base and technical capabilities of all parties. Groups are primarily driving their individual roadmaps. No top-down approach of bringing the chosen themes alive has been noticed during the visits to the research groups.

RECOMMENDATION: the Domain should take action to make the chosen themes alive in the whole research community, in a sustained dialogue between the research groups and the leadership of the Domain. Such an effort is important in order to produce a shared focus, content-based visibility and a lead for sources of financing. Examples from the past (e.g., the *zwaartepunt programma's*) may serve as examples.

Funding

The overall funding situation looks healthy at present but will need continuous attention for the future. The Domain EE at Delft has been very successful in attracting 3rd money stream funding, both nationally and internationally, often in cooperation with other departments and industry. Although there are obvious threats for the future (e.g., diminishing chances of success in the H2020 programme), the Domain should be able to bank on its experience with generating outside funding.

Leadership

All the Departments have provided and continue to provide clear scientific international leadership in several central areas of EE (corresponding to the topics covered by the Departments), as testified by a good number of *best paper awards* at major conferences, IEEE Fellow awards, impressive participation in the leadership of major conferences and IEEE societies, and a good number of other awards, e.g., VENI- VIDI- and VICI grants and ERC Advanced and Starting grants.

Staff

Looking at the numbers (scientific staff to student ratio), the workload must be high. Nonetheless, during the visits of the individual research groups, the Committee formed the impression that the workload is not considered an issue and that the staff is managing it well, thanks to the offering of TQE (Teaching Qualification Education) and the dedication of scientific staff primarily assigned to teaching. There is also a plan to reduce the burden by dividing the teaching load by assigning courses to two staff members, who alternate on a yearly basis.

Facilities

The Domain offers a variety of facilities, to wit: the Else Kooi Laboratory, the High Voltage Laboratory, participation in the new Kavli Laboratory (jointly developed with TNO), the Radar Laboratory on the roof of the main building, and many smaller facilities operated by various research groups. Although the larger laboratories (with the exception of the Kavli-lab) have existed for a long time, they also have been updated regularly, thanks to the acquisition of new equipment via the available money streams. The Else Kooi Laboratory has been developed into a separate unit within the Faculty, but it is still effective as a facility where new types of electronic devices can be fabricated and measured. It has engaged in new developments, e.g., for molecular electronics, the fabrication of bio-electronic devices as well as high-frequency and quantum devices. The High Voltage Laboratory is also being transformed to accommodate research on new generations of (sustainable and smart) electrical power systems, in particular in the generation and transmission areas. The Committee has been impressed by the dynamic re-development of these very useful facilities, which have remained of very good quality over the years. They deserve the full support both of the Faculty, the University and the Dutch authorities.

RECOMMENDATION: since the continuous financing of facilities that are eminently effective to supporting modern research in micro-electronic devices of various categories, and the fact that several research groups at TUD are showing a great international reputation in their areas of expertise, both the Faculty Electrical Engineering, Mathematics and Computer Science and TUD should set up a special directed effort to ensure the continuing financing and development of these well-chosen facilities (a similar recommendation is valid for the Domain of EE at Eindhoven and at Twente, see the general recommendation on this matter.)

PhD Programmes and Graduate School

The Graduate School (GS) is well structured and has a good mentoring programme. There is general PhD-student satisfaction over the supervision of their research as well as its embedding in national or international programmes. The Committee heard some criticism on duplications in the soft skill programme during the site visit. The PhD-candidates appreciate the English language and presentation courses highly. The master level offering of courses and lab facilities are experienced as very positive as well. The proportion of PhDs finishing within 5 years is insufficient. The Committee also learned from the interviews with PhD students that some students have mixed feelings about the added value of the GS, except for the language and writing skills.

RECOMMENDATION: a major effort is required to improve on the number of PhD-candidates who obtain their degree in at most five years, e.g., by early monitoring of progress and providing early assistance in paper and thesis writing (e.g., overcoming the *writer's block*).

Research Integrity

The control on science integrity and data logging looks very good and appropriate. The integrity issue does not seem to live so much in the community. Students have the possibility to skip the integrity courses which they sometimes do.

Lacking in the report is a policy on rights and duties of staff members and PhD students in industrial contracted projects, including IP rights.

Another integrity issue that is lacking is the policy with respect to the authorship of publications.

RECOMMENDATION: the Committee recommends that the Faculty (in conjunction with the University) adopts a formal policy concerning acceptance and dealing with industrial contracts (it is understood that all contracts are subjected to approval by the Dean of the Faculty). Similarly, the Committee recommends that the Domain of EE at TUD formally subscribe to the IEEE ethical rules with respect to publications.

Diversity

The Committee noticed that the Domain attracts a high proportion of international research students and staff. A question might be whether the TUD attracts a sufficient number of Dutch PhD students. The permanent staff is very diverse as far as nationalities is concerned.

Female to male ratio in the permanent staff remains too low, although in some research groups there is a reasonable balance. More affirmative action is clearly needed. No plan nor targets are formulated to address this issue.

Rejuvenation of the staff might be necessary. Although quantitative numbers were missing in the report, the Committee feels that the ratio BSc/MSc students to permanent staff is also high.

RECOMMENDATIONS:

- Formulate an affirmative action plan to attract more women in permanent staff positions, and combine this with a tenure track plan to increase the ratio of junior staff (at the assistant professor level) to senior staff (at the associate and full professor level). In particular, make use of your excellent international position;
- Formulate targets for these efforts;
- Investigate whether there is sufficient transition of Dutch students from the Master's level to the PhD programmes, and if not, what the causes might be.

Observations and Remarks concerning the Research Groups

Electronic Components, Technology and Materials (ECTM)

- Strong programme, strong leadership, strong long term financial position;
- Impressive external network, active and successful in influencing policies and programmes;
- Future of the group is secured by ample successful project proposals and awards. (e.g., *Zwaartekracht* award);
- Good gender balance in the group, both with staff and students;
- Group is contributing to a multitude of multi-disciplinary projects with first-of-a-kind technologies and devices;
- The EKL facilities are essential to the group. Equipment upgrades in EKL are essential for the future research domains in ECTM, and for the vast network of non-ECTM users.

Electronic Instrumentation (EI)

- Strong programme, strong leadership, strong long term financial position;
- Good balance of industrial and basic research in a wide range of silicon sensor applications and high precision analogue electronics;
- Group is running against the capacity limit of the fixed staff;

- Given the huge effort at many universities on (low-power) power management, we find it remarkable that the group elects power management as one of its new research fields. We advise to carefully identify the differentiating opportunities;
- The group supports its PhD students to maximum quality results and outputs and does not hesitate to prolong the relation with PhDs up to five year, convinced of the fact that this is mutually beneficial for the group and the PhD students;

BioElectronics (BE)

- Young, enthusiastic group with a compelling and ambitious research roadmap;
- Promising new microsystems are explored with physicians, that have the potential of opening new solutions in healthcare (e.g., a prototype implantable neurostimulator under development);
- Good gender balance in the group, both with staff and students;
- Group has high educational load, aggravated by their contributions on medical electronics topics in multiple master programmes. They are keen to see a reduction in this educational load by further increase of permanent staff;
- The conservative nature of the health-tech industry and of physicians are a latent challenge to the research roadmap. The group and its industrial partners will have to find a solution to the lengthy process of meeting compliance to the medical standards.

Electronics Research Laboratory (ELCA)

- Strong programme, strong leadership, strong long term financial position;
- Creative team, working on major innovations in multiple RF fields a.o., base stations, car radar, and mm-wave characterisation;
- Group is highly dependent on its technicians with their acquired crucial know-how of tools, equipment and methodologies complementary to the PhD expertises. Essential for the group to maintain its core of technicians;
- Group has a culture of successfully identifying and nurturing spin-offs.

Terahertz Sensing (TS)

- Medium sized group with an exceptional scientific track record (many good publications and best paper awards, 3 ERC grants, 2 NWO grants);
- Strong vision on research strategy and group organisation (e.g., 2 PhD students and 1 Post-doc per staff member). Close collaboration with other research groups in a very complementary way, very positive and efficient attitude (e.g., measurements, fabrication, …). Limited interest in patents (a.o., due to financing system and impact on open collaboration with international partners);
- Very restrictive in Master Student selection (care should be taken to balance the load between different research groups);
- Very much focused on fundamental research (TRL1&2) with a strong added value towards society (e.g., very strong collaboration with SRON, good contacts with TNO, ESA, NXP). The faculty themes are not seen as a key driving factor of the research strategy;
- Strong performance in timely finishing PhDs (4 years).

Microwave Sensing, Signals and Systems (MS3)

- Relatively new section (2011) with long standing research with unique expertise in radar and related experimental research. Clear vision on relevant future research challenges (in line with faculty themes). Good spin-off and patent activity;
- Very good scientific quality with very strong scientific output (a.o., best paper awards);
- Good mix of fundamental and more industry oriented research (e.g., Thales, NXP). Very good state-of-the-art research facilities. Well embedded in university wide research initiative (DSYS, Climate Institute);
- Very high teaching load (a.o. service education) but managed well;
- Good performance in timely finishing PhDs (4 to 5 years).

Circuits and Systems (CAS)

- Excellent scientific track record with many high impact publications and many contributions to the top conference in the field;
- Very strong international visibility (a.o., 2 IEEE Fellows, editor in-chief of top journals in the field, multiple times active as guest editor);
- Very clear view on research challenges that are relevant for industry and society, including shift of application areas: biomedical engineering);
- Would be good to consider a more suitable name for the current activities of the research group (especially: circuits part);
- Duration of PhDs could benefit from more proactive stimulation to terminate in 4 to 5 years.

Quantum Engineering (QE)

- One of the key challenges addressed in the Department is the emerging field of quantum computing and the related computer architectures. Based on the world class expertise in physics of quantum devices and the strong computer science and micro electronics research at TUD, it allows the group to build a worldwide unique position in the field;
- Because the research field is still in its infancy, the organisation of the research is also not yet crystallized. The site-visit convinced the Committee that the group is on the right track and that it consists of a very enthusiastic highly competent team with a very good scientific track record and a strong leadership;
- The unique support by Intel is a clear recognition of the research group,
- The integration in QuTech is very important;
- The work on non-quantum topics is also very good and has a clear short term societal and economical impact;
- The societal impact of quantum engineering is expected to be very important in the more distant future;
- The impact on the more classical domains has to be carefully managed (drain from other research groups towards quantum computing group).

Intelligent Electrical Power Grids (IEPG)

- IEPG research mission focuses on the digitalization of the electrical grid infrastructure, which is undergoing major changes due to renewable power sources (wind and PV) for a sustainable energy supply. Characteristic is the system-oriented approach. The research programme covers the three different time scales: steady state, dynamic and transient behaviour of power systems. It includes not only technical but also economical and societal performance of the electricity supply system. IEPG has a solid base of industry research partners, among others, TSOs and equipment suppliers (TenneT, Siemens and GE) to support the digitalization in the energy sector;
- Future research plan: protection of meshed grids is becoming a major research topic and IEPG is contemplating an international centre (with industry partners) in this area. Workshops and data exchange between partners and grid planners are crucial for coordination of protection schemes of future transmission and distribution grids. DSOs have internal strategies about digitalization (in competition to Google, etc) but need help. They expect that the research activities of IEPG connect to their strategies. To facilitate this, several part-time researchers are working with IEPG (Tennet, Centrum Wiskunde & Informatica). Data security is also a topic of research in cooperation with international groups;
- Spin-offs and patents: could be improved, but are deemed to be very difficult as the research output translates in control algorithms that are difficult to protect. Spin-offs have been created or are planned in the area of "smart circuit breakers" and simulation tools that have been developed for grid protection schemes;
- More master students and PhD assistants are needed to conduct the research in this growing field. IEPG is working towards increasing its visibility at faculty and department level to attract more students and space.

Photovoltaic Materials and Devices (PVMD)

- PVMD is leading the Solar Urban Programme in which all the ESE sections work together. The PV-part developed PV cells with 23% efficiency, which is the highest efficiency of its kind in NL and possibly Europe. The section works on modelling tools to predict yield of PV farms;
- Start-up companies have been created: one company is very successful on large area solar simulators. Another company delivers measurement equipment on spectral measurements. With ECN cooperation is ongoing to develop production machines (for PV);
- The activities at Tsinghua University in Beijing, China, are co-financed by the city and are remarkable;
- Issues are raised with the cost of the clean rooms (former DIMES, now Else Kooi Lab) and the reduced funding by the university. However, the Solar Urban programme could bring the PV production technology back to the Netherlands. The faculty should give more space to deploy the activities of Solar Urban, as this attracts lots of Dutch students.

DC Systems, Energy Conversion & Storage (DCE&S)

- DCE&S works on disruptive technologies, such as DC grids, LV DC, power electronics and storage systems. Six research areas are supported by eight Assistant Professors. The group has 30 PhD researchers. A clear roadmap for DC technology in the distribution grid was developed. Strategy meetings with the sister sections are regularly held to develop the roadmap;
- The delay of the construction of the low-voltage DC laboratory (by two years) impacts the planning of projects and impedes the roadmap. The faculty should help more to speed up the construction of this so-called ESP lab;
- Spin-offs are encouraged but are limited. For example, EPYON, now bought by ABB, is a nice example. Cooperation with companies in Technopolis is a positive development. The group works on demonstrators that reach TRL3 to TRL6.

3.2 RESEARCH AT THE FACULTY OF ELECTRICAL ENGINEERING, EINDHOVEN UNIVERSITY OF TECHNOLOGY

Faculty Dean	Prof. dr. ir. Bart Smolders
Research staff 2016	64.0 Research FTE (excluding PhD and PDEng)

As mentioned in the self-assessment report, the mission of the *Faculty of Electrical Engineering at the TU/e* (further to be called EE) is to acquire, share and transfer knowledge and understanding in the whole field of "Electrical Engineering" through education, research and valorisation. The Faculty aims at being a research-driven and design-oriented world-class institute by having education, research and valorisation reinforce each other. Activities share an application-oriented character, a high degree of complexity and a large synergy between multiple facets of the field.

The research groups perform (mostly) mono-disciplinary research and provide continuity. On top of the groups, the following types of interfaces have gradually developed:

- An Institute as an interface from the groups to other departments or universities;
- A Centre as an interface to industry;
- A Theme as an interface to society at large, especially to secondary school students, but it also provides internal focus for the groups.

The three themes presently chosen are:

- *Connected World*, covering technology for wired and wireless data transfer for communication and connectivity, and with a focus on future integrated communication infrastructures.
- *Care & Cure*, covering technology for remote diagnosis and health monitoring of people, for early detection of diseases and for enabling elderly people to stay in their homes reaching higher ages with better quality of life while reducing costs.

- *Smart & Sustainable Society*, connecting all technology for more efficient and more sustainable ways of generating and consuming energy, thus providing high-tech solutions for turning our society into a society where a large population lives in harmony with nature without depleting resources and without leaving lasting footprints for next generations of mankind.

The research outlay was composed in 2016 of 35.8 FTE scientific staff, 28.2 FTE post-docs and 161.4 FTE PhD-candidates.

Table 7 shows the demonstrable research output of the Faculty EE.

	2011	**2012**	**2013**	**2014**	**2015**	**2016**
Refereed articles	224	243	267	214	238	245
Non-refereed articles	1	0	1	1	7	8
Books	18	5	6	3	3	2
Book chapters	21	30	31	11	9	18
PhD theses	29	30	41	42	37	36
Conference papers	507	395	459	435	450	350
TOTAL	**800**	**703**	**805**	**706**	**743**	**659**

Table 7: Total output of the Faculty EE

The composition of the research staff of EE is found in Table 8.

	2011		2012		2013		2014		2015		2016	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff	97	27.5	102	28.1	108	30.0	116	30.7	111	33.2	117	35.8
Post-docs	39	24.6	35	24.4	39	24.8	39	28.7	45	33.0	38	28.2
PhD-students	136	108.3	148	116.5	171	123.8	180	137.4	179	143.1	202	161.4
PDEng	16	6.9	20	9.0	24	10.8	26	10.9	20	10.0	15	7.5
Total research staff	**288**	**167.3**	**305**	**177.9**	**342**	**189.4**	**361**	**207.7**	**355**	**219.2**	**372**	**232.8**
Support staff	48	43.8	54	48.7	41	36.3	46	39.7	46	38.8	46	39.6
Visiting fellows	0	0	0	0	0	0	0	0	0	0	0	0
Total staff	**336**	**211.1**	**359**	**226.6**	**383**	**225.7**	**407**	**247.4**	**401**	**258**	**418**	**272.4**

Table 8: Staff embedded in EE

The total funding of EE is found in Table 9.

TOTAL	**2011**		**2012**		**2013**		**2014**		**2015**		**2016**	
	k€	%	k€	%	k€	%	k€	%	k€	%	k€	%
Direct funding[1]	10441	4	9332	37	9424	34	9269	33	9242	33	10689	36
Research funding[2]	2207	9	2791	11	3955	14	3830	14	4442	16	4606	15
Contract research[3]	11017	43	11137	44	12692	46	13773	49	13355	47	12975	43
Other[4]	2028	8	2106	8	1165	6	1271	5	1167	4	1337	4
Total funding	k€ 25629		K€ 25365		K€ 27736		k€ 28143		k€ 28206		k€ 29607	

Table 9: Total funding at level of EE. All amounts in k€.

1. Direct funding by the University, obtained directly from the University, and financial compensation for educational efforts.
2. Research funding obtained in national and international scientific competition (e.g., grants from NWO, KNAW, EU/ERC, ESF).
3. Research contracts for specific research projects obtained from external organisations, such as industry, government ministries, the European Commission, and charity organisations.
4. Funds that do not fit the other categories.

Research area, objectives and organisation of the research

The Domain of EE at TU/e offers a clear definition of research areas, covered by a set of research groups with strong past research traditions. The Committee has been impressed by the strategy proposed by the Domain, the strong scoping of its topics and its strong positioning in the technological hotbed of greater Eindhoven. The three main themes (*Care&cure*, *Connected world* and *Smart sustainable society*) are clearly important and well-chosen. Notice that *Care&cure* appears as a theme in the two other locations as well, which invites to collaboration and local focussing.

At the critical side, the report is generally lacking a vision on the main scientific and technological challenges, and research questions the Faculty wants to address in the near and medium-term future. During interviews with the groups, the visions of the individual groups were clarified well to the Committee.

To enhance internal and external collaboration, the Domain has created *Centres* that are collaborative efforts of research groups in specific areas that need multi-disciplinary efforts and facilities, and are well positioned for collaboration with industry as well. The groups look at the Centres and their function as an interface with industry very positively. The shared laboratories operate as a physical space for collaboration between the groups in a Centre. The Centres have a chairperson and a small staff.

During the interviews, it became clear to the Committee that the Themes are used for documenting the societal motivation for the research, e.g., to potential EE students as well as to industry and society at large. But the role the Themes play in the conduct of actual research remained unclear.

RECOMMENDATIONS:

- A clear formulation of research challenges and technological issues connected to the chosen themes and implemented by the Centres would enhance the visibility of the research and provide interest in cooperation by industrial partners as well as motivation for financing by public and private authorities.

- In a similar vein, an inventory of the *need for knowledge in EE*, attuned to the Eindhoven area would be helpful in further focussing the strategic choices of the Faculty (both directed to research and education).

RESEARCH QUALITY

The scientific output shows a *very good* overall performance, with several peaks of excellence. EE at TU/e has shown impressive performance in a number of top areas, many groups and senior scientists have sturdy international reputations, as evidenced by top publications, important rewards and international recognition.

The emphasis on journal papers has been successful. However, the Committee has the opinion that conference papers and participation in the main conferences in the respective fields should remain essential for the research groups to stay on top of the fast development of research and to provide sufficient exposure to and for the researchers (in particular the PhD students and Postdocs).

The average h-index is 16 and 25 authors have h-index over 30. In engineering areas these are very good. However, a large number of staff members has a rather low h-index (<10). The publication track record is very good to excellent in some groups. On the average there are 4.1 journal papers/ total research FTE staff member and 7.4 conference papers/ total research FTE staff member.

RELEVANCE TO SOCIETY

Excellent links exist between industry and the six Centres. The Centres are used to bridge the gap between research and industry. There is a very impressive programme of staff interchange and interaction with industry. The Committee learned from the interviews that staff is being stimulated to build up a sustained relationship with industry.

The construction with IPI and PITC to foster a coherent cross-faculty programme and deliver solutions is commendable. Investment level must be high, so the need for tangible results is also high. When large activities on higher TRL levels are envisaged, it might be beneficial to follow the IPI + PITC structure (in order to keep the lower TRL research close to the research groups).

Facilitation of spin-offs can be strengthened.

The topics that are covered by the various research groups do support the three areas that are relevant for society. The extensive collaboration with research staff in industry allows for a very good estimation of the needs for knowledge in the industrial environment. Nonetheless, the external *need for knowledge and expertise* could be made explicit and documented to increase visibility.

RECOMMENDATIONS:

- The Committee recommends to make the TU/e technological assets and competences more visible e.g., on the internet. A good example for this is the Energy Landscape data base from the Jülich-Aachen-Research-Alliance (JARA);
- Concerning facilitation of spin-offs and patents: the Committee advises to put a strategy in place to assist the creation of spin-offs and to provide means towards implementation (e.g., innovation scouting, allowing *resident entrepreneurial scientists* or patent filings with the Innovation Lab, aiming at valorisation through spin-off).

VIABILITY

Governance

The Committee has observed a further consolidation of the governance structure of the Domain: the role of the Centres as associations of research groups to provide a united interface in major areas and to run joint laboratories has been strengthened. The usefulness of the Centres in providing leadership and attracting interest from industry and society for collaborative projects has been proven. This method of governance seems to strike a good balance between the vertical capacity organisation of the domain, and the need for a horizontal, project-oriented development of multi-disciplinary and collaborative projects, driven by the 2^{nd} and the 3^{rd} money streams.

The relation between IPI, the corresponding Centre PITC, the clean room facility Nanolab@TU/e, PhotonDelta and the participating research groups has been clarified to some extent, although the future organisation is still in flux and in the process of consolidation. TU/e offers a major contribution to the development of photonics technology worldwide and deserves strong support for its photonic facilities both from within the University and from the outside world (public authorities and industry). It will remain a major challenge to sustain their growth, the quality of the equipment and the ability to stay at the forefront of Photonics, but the burden should not be born exclusively by the Domain or TU/e.

The text enumerates the standard modern themes motivating research in EE (in particular: aging society, the incidence of biology, future of energy, mobility) but a more effective way would be to formulate the modern challenges for EE research. The central research issues, how they can be tackled and what that means for the future constitution of the Faculty is a task the Centres should engage in.

It is good that the Domain recognises that there is an unbalance in the workload between the groups and that this is taken care of.

RECOMMENDATIONS:

- The Centres are an eminent place to make the research goals of the Domain clear and visible both internally, for motivation, and to the outside world, for attracting interest and funds. The Centres are advised to collect and define the research goals, make them visible on the internet and provide effective means of access;
- [For the three Domains] The Committee advises the Domain to compare its choices of research topics, scientific challenges, and organisation with major other players in the field (e.g., MIT, Stanford, KU Leuven, RWTH, ….) and how other major scientific domains address their environment, e.g., visibility (astronomy, medicine, physics, chemistry, …). The Committee does not advice to necessarily copy these, but knowing what the *competition* is up to is valuable information, both for focussing one's own choices and for not missing out on important developments in knowledge and expertise;

- The position of large facilities like Nanolab@TU/e and (in the future) PITC and their relation to the Faculty is from various points of view a critical issue. It may drain the resources of the Faculty considerably, or else the facilities might lead a subcritical existence when not properly funded. The Committee recommends the Domain to further develop a viable policy on this issue, also in view of potential further initiatives towards the creation of new laboratories. Recognition of the facilities for photonic integration as a major international Centre of Excellence should help to alleviate the financial burden on TU/e and ensure a sufficient level of financial support by public authorities in the future.

Future strategy

Given the success with the present mode of operation, it is appropriate to keep the main lines of research and further strengthen the present organisational approach. Limiting the ratio of temporary to permanent staff to about three is very good. A good opportunity exists to grow in staff. It is a good strategy to focus on expanding existing teams and not creating many new teams with low critical mass, but to allow the exploration of new avenues within the existing teams, often in collaboration with other laboratories in- or outside TU/e.

The strong emphasis on personal grants and TRL1-2 funding is seen to form a necessary base for higher TRL research. Higher TRL research via Centres is appropriate (but at present not very clear in terms of organisation). The various groups evidently strive at a combination of lower and higher TRL, but the Committee got the impression that in many groups most of the research is at higher TRL (levels 5-6). This is not considered a major problem as higher TRL research can be very creative and original, but sufficient attention and funds have to be devoted to the more fundamental research as well, in particular in view of the building up of a strong scientific knowledge position. An exception is to be found in the Institutes, which are devoted to the development of basic technology, a combination of fundamental and TRL level 3-4 research.

The approach towards staff workload, and especially regarding teaching load, is appropriate and should be monitored.

The outreach of TU/e Faculty to industry is excellent. EE benefits from a powerful local eco-system. Additionally, the Committee also considers the willingness to collaborate and align on programmes as essential. Close cooperation with sister departments is valued to optimize scarcer 1st money stream resources, for example, sharing complementary expertise and technological facilities.

RECOMMENDATION: the Committee recommends to strengthen the vision on the future of the Faculty on a number of items:

- The role of Centres and Themes;
- The formulation of central scientific challenges an research questions to be addressed;
- The development of the future knowledge position the Domain and its research groups is striving to achieve.

Funding
RECOMMENDATION: the consolidation of funding in the 2nd and 3rd money streams will remain a key challenge. The Committee recommends to strive for better visibility, and more intense political work from the faculty leadership (this is no criticism, it is a necessity).

Leadership
TU/e shows very strong international leadership in several specific areas with a major effort in Photonics. The Committee learned from the visits of the research groups that the four criteria on which staff is assessed is sometimes felt as unclear, because the targets are not clearly set, and this causes stress for staff in tenure track positions

RECOMMENDATION: the Committee advises to set more concrete targets for the staff promotion criteria.

Staff
Finding highly qualified researchers remains a problem.

RECOMMENDATION: the TU/e permanent staff in EE is largely Dutch. The Committee advises the Domain to tap the international market more intensely, especially (and not restricted to) for junior (tenure track) nominations, and this without compromising quality. It makes the hiring pool much larger and there is a large group of very talented post-docs searching for tenure-track positions internationally. This strategy may increase both the junior-to-senior and the female-to-male staff ratios (not to talk about the international ratings).

Facilities
EE has great facilities, at least the ones the Committee visited in their new building. The new building, with its open space, encourages cooperation between the different groups. It is recommendable to make these facilities more visible on the TU/e webpages, as it would attract more students and young staff.

PhD programmes and Graduate School

The numerous student teams add value to the curriculum and the Committee hopes it gives many students a more entrepreneurial mind-set. The start of the Graduate School for a PhD student is very positive. PhD students are encouraged to follow summer courses or graduate school courses, which seem to be available in most fields. A dropout rate of 20% and some years even 30% is seen as high. In addition, the target of 80% of the PhDs to graduate within five years has not been met, not even closely.

RECOMMENDATIONS:

- Find the root causes for the large drop-out rate and decide what to do about it;
- The ratio of PhD candidates graduating in less than five years' time is much too low. Stringent action (e.g., closer control on progress, better assistance in writing and publishing skills) is necessary. Thesis advisors may also be pushing for more results at the cost of thesis production. This tendency, if it occurs, should not be tolerated, as it is detrimental to the PhD-candidate, who already enters the job market at a relatively advanced age.

Research Integrity

EE has implemented the university wide integrity policy. The text of the report, however, neglects important topics like:

- What the position is of staff researchers and PhD-students in collaborative projects with industry;
- Who is owner of IP rights derived from funded and collaborative research;
- Who is allowed to be author of a publication;
- What is good practice, what is regulated;
- How conflict situations are handled.

RECOMMENDATIONS:

The Committee recommends:

- To define, adopt and enforce a policy concerning the acquisition of 3rd money stream projects as far as their content is concerned and the right and duties of its staff;
- Similarly concerning IP;
- To adopt the IEEE rules concerning authorship of publications.

Diversity

The measures proposed to redress the unfavourable female/male ratio seem insufficient, given the results so far (the report states that there are about 5% female professors in 2016, and the target is 20% by 2020). Measures to achieve this target are not sufficiently detailed. The Committee reads an ambition to improve the numbers, but no plan has been drafted so far. Much more drastic actions are needed, in particular affirmative actions in prospection and hiring.

The permanent staff of the Domain is mainly Dutch. However, most PhD candidates are from outside The Netherlands.

RECOMMENDATIONS:

- See our recommendation concerning international hiring, where a much larger pool of potential top level female candidates is available. Hiring internationally would also increase the overall international diversity of the Domain;
- The visibility of societal goals, areas of expertise and important research questions may improve the visibility of the Domain for aspiring young students and thus improve the diversity in the (graduate) student population.

Observations and Remarks concerning the Research Groups

Generic remarks, valid for all research groups in the three Domains

- Starting scientists (assistant professors?) experience challenges with new fields of research. Dutch funding is largely dependent on industry interest, which is not obvious to them in the beginning. A starting grant funding for 1 or 2 Ph.D.'s and a post-doc position for five years would be helpful [this recommendation is general for the 3 Domains];
- Recruitment of industrial experts into the academic research is hindered because the grants system is based on traditional scientific career track (scientific publication profile, h-index);
- It was mentioned that lot of the *research time* needs to be spent on project writing and acquisition, but with little success rate (5%), resulting in an inefficient use of PI efforts.

Mixed-signal Microelectronics (MSM)

- Very enthusiastic about cooperation in the Centres. Working with and impacting on the Centre roadmaps;
- Very good relation with industrial partners, maintaining a broad research eco-system leading to many research results;

- Care is taken to safeguard the experience created by a PhD for after their leave, by keeping available documentation and measurement board (HW, SW);
- Roadmap for longer term upgrading and maintenance of impressive and well organised measurement facilities.

Photonic Integration (PHI)

- Impressive combination of different technologies, and expanding to membrane technology. With the clean room facilities and measurement setups, the group has a unique set of capabilities at its disposal and is making very good use of it;
- The high costs for running the Nano lab is shared by multiple faculties and industrial partners, adding up to 60 researchers in total with 10 working on photonic integration; We believe this improves the long term viability of this facility and thus is beneficial to the integrated photonics roadmap;
- The synergy with the PITC will enable new opportunities for both the PhI group to do advanced research as well as for PITC to deliver solutions to the industry. We consider this organisational setup to be valuable and promising;
- The group needs to identify the right enabling IP model in order to feed the industrial eco-system. The presented willingness to open up IP in a controlled way with as little as possible entrance barriers, is a very good approach;

Electronic Systems (ES)

- Very strong track record of long term collaboration with industrial partners;
- Strong programme, strong leadership;
- ES contributes in several Centres, there is room for improvement in the contribution to CWTe because of a long lasting vacancy. We advise to explore alternative approaches to come to a good resolution of this vacancy and a strengthening of the collaboration in the CWTe;
- The group employs 10 full time staff and 10 part time staff. Funding is partly based on 3rd money stream industrial collaboration. The funding

situation is sound, but there are risks if over time the 3rd money stream would reduce.

Electro-Optical Communications (ECO)

- Excellent scientific quality and output with high number of top journals and top conferences in the field. Also a large number of personal grants (ERC and NWO), 3 fellow titles and strong participation in EC projects;
- State-of-the-art lab infrastructure in optical systems characterization;
- Longstanding tradition in multidisciplinary research started in COBRA and now in IPI. Promising approach with respect to moving to higher TRL levels by creating a linked Centre (PITC) and working with industry (exact interaction mode IPI and PITC may need special attention);
- Strong performance in timely finishing PhDs (4 years).

Electromagnetics (EM)

- Teaching load appears very heavy (this is the major cause of staff high workload), initial measures taken at both PhD student and staff level (distribution to other research groups), further attention required;
- State-of-the-art lab infrastructure in EM measurements (also unique homemade set-up);
- BioEM: Excellent scientific results in hyperthermia, other research fields in BioEM very good (but may need clearer positioning with respect to peer international research teams). Excellent research in antenna design;
- Strong links with important local industry players;
- Good complementarity with EM focused research activities at other TU's.

Signal Processing Systems (SPS)

- Very strong and important link with medical partners;
- Ratio of staff members with respect to PhD students is much below 1/3, but this is partly resolved by strong guidance from industry;
- Strong track record in spin-off creation;
- Excellent national and international scientific recognition (5 IEEE Fellows, ERC and NWO research grants).

Electrical Energy Systems (EES)

- At societal level, EES's research mission focuses on solutions for a sustainable society. To accomplish this strategy, EES creates and transfers knowledge to society in a variety of ways (students, industrial projects, etc.). EES has a solid ecosystem of research partners, among others, TSOs (TenneT) and DSOs (Enexis) to support the energy transition. This cooperation is exemplified by adjunct professors from Tennet, TNO and DNGL. On the digitalization side EES works on aggregators (= coupling sectors) and has cooperation with KPMG supporting PhD work in the area of ICT, consulting;
- Future research plan: data is becoming more and more important. SMEs are interesting to develop low cost sensors. EES sees lots of opportunities for diagnostics and preventive maintenance of infrastructure;
- Spin-offs have been created in the area of "smart high-voltage cables", pulsed power for plasma generators that provide clinical disinfection for greenhouses, thereby avoiding pesticides. Bio-electric systems potentially open up new research areas. Another example is a simulation tool that has been developed for power flow calculations in distribution grids;
- Conclusion: EES's mission fits well in the societal vision of the Department (sustainable energy). EES has a clear understanding of its capabilities and competences to make substantial contributions to its mission. The research topics have strong relevance to a variety of societal issues (even on the clinical and medical area). Two main research areas are combined: high-voltage materials and components (actually high field strength research) and smart grids. In the latter area EES cooperates with other TU/e research groups (in particular EPE and CS), national (TUD) and international research groups (in EU projects). To support the high voltage research a tenure track assistant professor is planned.

Electro-mechanics and Power Electronics (EPE)

- EPE grew fast over the past years (more than 55 researchers, 2 Professors, 3 Assistant professors and 15 adjunct professors). EPE has two major research areas; ultra precision electro-mechanical systems (mechatronics) and power electronic converters. EPE is leading a Centre on High Energy Systems and is co-directing the High-Tech Systems Centre. EPE stresses that the cooperation in the Centres helped to increase research and visibility towards the industry and society. New research activities in superconductive machines is very advanced. Strong cooperation with TUD and UT. EPE works with several industrial partners;
- Research is multi-disciplinary. In most projects experimental proof is required. This often prolongs the PhD work. EPE has the possibility to support PhD assistants with their thesis when, due to circumstances, the PhD experimental work needs extra time (due to external factors, e.g., when components are delivered late);
- One spin-off of EPE is very successful (ProDrive). This company picks up several patents. EPE works on demonstrators (TRL 6). This is justified due to the fact that their work is pushing the limits of the components, measurement accuracies and even the simulation modelling capabilities of the systems;
- Conclusion: in the area of high-precision and high-speed positioning actuators and magnetic levitated actuators the research and development at EPE is world class. The group also develops highly-efficient dc/dc converters, controls and permanent magnet drives. The cooperation in the TU/e EE Centres has created many opportunities to cooperate with the other research groups at TU/e. No doubt, the strategy of the Department to develop the Centres and bring all EE groups in one building has facilitated this cooperation, leading to the strong growth of EPE.

Control Systems (CS)

- CS works on scientific domain of systems and control providing essential tools for high-performance automated operation of technical systems. The fundamental research covers system identification, study of spatial-temporal systems, networked and distributed control and model-based control and optimization. The applications include control of smart power grids, automotive applications, control of high-precision (nano-meter) linear motors and process control. The group has lots of cooperation with other groups via Centres;
- CS has 28 PhD researchers working on four domains. International visibility is high as witnessed by the awards and standing of the faculty in IEEE. The High-Tech Centre helped to facilitate strong cooperation with other research groups at TU/e and industry consortia.
- Future plan is to focus more on system level control topics, managing complexity and data analytics for information identification;
- Conclusion: the strategy of the Department to develop Centres has helped CS to gain strong partnerships with other research groups within TU/e, in particular with EES and EPE, and in High-Tech Systems Centre initiated by CS. The results have fostered development of control engineering solutions that support and have strong impact on the societal problems in mobility and sustainability.

3.3 Research at the domain of Electrical Engineering at the Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente

Faculty Dean	Prof. dr. Peter Apers
Research staff 2016	42.7 Research FTE (excluding PhD)

As mentioned in the self-assessment report, the mission statement for research at *the Domain of Electrical Engineering at the Faculty of Electrical Engineering, Mathematics and Computer Science at UT* (further to be called EE at UT) is to find fundamentally new solutions to practical problems in society using advanced knowledge and technology in EE. In this effort, the Domain involves and trains young scientists to acquire a leadership position within the broad spectrum of topics for which advanced knowledge in electrical engineering is important. Right at the intersection of the research Institutes MESA+, CTIT and MIRA, EE at UT envision the field of electrical engineering primarily as the place where *bits meet nature.* In this context *nature* is the real world we live in with physical activity, social action, and exchange of information. The virtual world of *bits* is related to pure information handling. From this vision EE takes a central role in almost every modern digital system. In setting the scientific and societal relevant research goals, this also means that the research will have *bits* aspects as well as *nature* aspects. With this in mind, EE at UT defined two main directions of its research:

1. Electronic Systems

Regarding electronic systems, the focus is very much disciplinary in the heart of EE. The research envisaged will provide new electronic components, electronic circuits and embedded systems, including sensors, actuators, and physical communication channels.

2. System Applications

Regarding system applications, EE focuses specifically on those applications, which will integrate the electronic devices into natural and societal systems, thereby aiming at the achievement of sensible improvement and impact.

Upcoming characteristic developments are the Internet of Things and 5G-communication, which are bringing a wireless and embedded computing component in nearly any product and system. Health is an important application for EE research at UT and is also a clear field where bits meet nature. This varies from developing technologies to assist people, as well as new devices for medical diagnosis, cure and care. Robotics is expected to further evolve, and even disrupt society. Robotics forms an important field for EE at UT with a strong interaction between electronics and mechanical engineering.

The research outlay was composed in 2016 of 17.6 FTE scientific staff, 25.1 FTE post-docs and 93.4 FTE PhD-candidates.

Table 10 shows the demonstrable research output of the EE at UT.

	2011	**2012**	**2013**	**2014**	**2015**	**2016**
Refereed (journal) articles	157	149	191	173	186	154
Non-refereed articles	9	6	4	5	5	2
Books	0	0	0	1	1	2
Book chapters	16	11	7	13	14	5
PhD theses	38	20	41	46	36	32
(Refereed) Conference papers	240	210	174	225	192	168
Invited conference papers	14	17	11	7	3	6
Professional publications	11	2	2	2	0	0
Publications aimed at the general public	3	0	0	1	1	1
Other research output <e.g. patents>	12	2	7	6	3	3
TOTAL	**500**	**417**	**437**	**479**	**441**	**373**

Table 10: Total output of EE

The composition of the research staff of EE is found in Table 11.

	2011		2012		2013		2014		2015		2016	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff	77	23.7	69	21.5	67	20.7	54	16.5	56	16.7	58	17.6
Post-docs	52	39.1	53	39.3	43	32.2	44	30.2	46	29.7	39	25.1
PhD-students	149	117.2	162	144.4	125	110.6	125	95.5	121	90.5	124	93.4
Total research staff	**278**	**180**	**284**	**185.6**	**186**	**162.6**	**222**	**142.7**	**222**	**136.9**	**221**	**136.1**
Support staff	45	32.5	41.6	30.2	37	27.5	31	21.6	30	21.2	27	19.1
Visiting fellows	0	0	0	0	0	0	0	0	0	0	0	0
Total staff	**323**	**212.5**	**325**	**215.8**	**291**	**190.0**	**254**	**163.7**	**252**	**158.0**	**248**	**155.2**

Table 11: Staff embedded in EE

The total funding of EE is found in Table 12.

TOTAL	2011		2012		2013		2014		2015		2016	
	k€	%	k€	%	k€	%	k€	%	k€	%	k€	%
Direct funding[1]	8580	35	8562	37	7678	37	7439	40	7443	43	8504	47
Research funding[2]	4350	21	4840	21	4227	21	4218	23	3568	21	4380	24
Contract research[3]	11321	54	9442	41	8665	42	6956	37	6352	37	5315	29
Other[4]	0	0	0	0	0	0	0	0	0	0	0	0
Total funding	k€ 24251		k€ 22844		k€ 20570		k€ 18613		k€ 17363		k€ 18198	

Table 12: Total funding at EE. All amounts in k€.

1. Direct funding by the University, obtained directly from the University, and financial compensation for educational efforts.
2. Research funding obtained in national and international scientific competition (e.g., grants from NWO, KNAW, EU/ERC, ESF).
3. Research contracts for specific research projects obtained from external organisations, such as industry, government ministries, the European Commission, and charity organisations.
4. Funds that do not fit the other categories.

RESEARCH AREA, OBJECTIVES AND ORGANISATION OF THE RESEARCH

The choice for More than Moore is almost evident, and was probably also the path the groups already were following. Another choice is provided by the mission statement: “bits meet nature”. Both are pretty statements but remain rather general, and hence do not provide real focus. More focus can be provided by formulation of concrete scientific and technological challenges EE at UT wants to achieve.

The three areas of EE covered by institutes (digital society, health and advanced materials, and nano-devices) are clearly of great importance. The potential impact of developments of EE on the future of society is a motive that appears in much of the activities of the research groups. This goes actually way beyond *bits meet nature* and involves developing technologies to make systems more intelligent or to achieve new potential (e.g., connection sensing, data handling and actuating, or creating organs-on-a-chip).

The Committee was informed that the financial and Human Resource Management (HRM) were shared between the Institutes and Faculty during the period of assessment. As of January 1st 2018, the Faculties will have complete responsibility for the research groups financially and concerning Human Resource Management. The main focus of the Institutes will henceforth be completely external: to generate (and manage) collaborative projects, establish links to industry, to scout for external funding and to take care of the embedding of the research in society. This will be the new main way of organisation. The motivation for this move is both practical (the simplification of financial streams) and strategic (the necessity to facilitate multi-disciplinary research efforts, to manage shared facilities and to establish clear interfaces with the outside world).

The three university-wide Institutes offer a great cross-functional approach. Many research groups in EE are favourable to the existence of the Institutes and happy with the financial simplification envisaged. They actively use the Institutes to create multidisciplinary collaborations.

RECOMMENDATIONS:

- The Committee advices to put effort in the definition of scientific and technological challenges and goals which the research in EE at UT wants to achieve, in order to put more focus into the very general choices of *bits meet nature* and *More than Moore*. Such an effort would increase visibility and motivation. It should be regularly updated in the light of achievements and new challenges, both from society and from technology;
- The Committee advices an evaluation of the newly proposed method of governance after a period of at most a year. The well-functioning of the Institutes is of great importance to the future health of the Domain, and the proposed actions may lead to a weakening of their executive strength (keeping in mind an old Dutch saying: *wiens brood men eet diens woord men spreekt, i.e.* one follows the will of the money provider!). The change in strategy may be very beneficial, but it needs the enthusiastic support of the participating research groups, which is anticipated but should be verified in time.

Research quality

The Committee is generally very impressed with the quality of the research in EE at UT. EE at UT has developed over the years a worldwide recognized reputation in several key areas, notably the areas covered by the three Institutes, but also in other key fields the Committee has found research of high international reputation. EE at UT has also shown very strong international and national leadership in all those areas as is testified by ERC grants, international collaborations, major research grants and a strong collection of awards obtained in the review period.

Concerning output in publications: the aim has been to shift the emphasis from conference papers to journal papers. This has succeeded quite well. In spite of staff reduction, the number of published journal papers in 2016 (157) is almost the same as it was in 2011 (154). The number of refereed conference papers is now lower (in 2016 there were 168 conference papers) than they were in 2011 (240). In some fields, conference papers are valued as high or higher than journal papers.

The overall performance is very good with peaks of excellence. There is a very good coverage of important journals and conferences. On the average there are 3.2 journal papers/ total research FTE staff member and 4.1 conference papers/ total research FTE staff member. Also, there is a very good output in number of PhD students. The impact factors are very good with peaks of excellence as well.

The number of spin-offs during the evaluation period 2011-2016 is 16, as the Committee learned after an update of the data. This number is seen as very good. From the interviews the Committee learned that the number of spin-offs is no goal in itself anymore. EE now focuses more on high potential i.e. the possibility to grow fast.

EE research has resulted in many technical products, insights and expertise. These include tools, instruments, software, infrastructure, prototypes, designs and data sets for peers.

There are commendable joint research activities with Max Planck and Fraunhofer Institutes.

The average h-index is 21. The median is 15. This is to be considered *very good* for an engineering discipline, although there is a good number of staff members in the below 10 category.

RECOMMENDATIONS:

- [For the three Domains, but especially for the UT] The Committee considers attendance at major conferences to be very important in order for researchers to stay abreast of scientific and technological developments, dispose of a forum on which to present their results, subject themselves to international criticism and improve their visibility. This is particularly important for doctoral candidates. Although the Committee values publication in the top research journals very much, it advices the research groups to keep motivating their staff and PhDs to remain very active in the conference (and workshop) circuit;
- After having received an update on the number of spin-offs the Committee is of the opinion that EE is doing very well here. However, to facilitate spin-

offs in the future, the Committee advices the Institutes to create additional support for budding scientists-entrepreneurs, to facilitate their residence in the research units and to set up a system of patent provision to protect their IP and diminish their risks as has been initiated in the TOP programme in Novelt.

Relevance to society

The programmes of the three main Institutes are highly relevant to society, and cover areas in which UT has a very strong international reputation.

There is excellent collaboration with the Twente environment, as exemplified by the activities in the neighbouring industrial park and the many relations between companies located there and the UT.

The level of 3rd money stream has diminished considerably, due to policy developments (in particular the disappearance of FES financing from the Dutch government). Some groups could effectively expand in the direction of contract research, but are hesitant to do so, preferring the 2nd money stream as more prestigious and allowing more freedom for the researchers involved.

The *Analog Hotspot Twente* is a nice demonstration of recognition from industry of the expertise delivered in the form of MSc and PhD students from the ICD group. The Committee considers this a very good achievement and a good model for others at UT and at other Domains.

RECOMMENDATIONS:

- Branching out into contract research may prove to be a necessity in the future to secure the financial position of research groups and Institutes. This kind of research may not be as demanding in organisation and overhead as feared by some research groups. When done well, the overhead could even be less, and the research questions more interesting than anticipated. However, it does require energy and an entrepreneurial spirit to establish interesting contacts and define scientific valuable goals that are also of interest to the participating companies (such a win-win situation is necessary to insure feasibility of the contract and justify the use of internal means). The Committee advices the research units to carefully consider possibilities in this direction, and the Faculty to facilitate the process.

- The individual research groups could engage in creating spin-off's by offering the possibility of *resident entrepreneurial scientists*. It may also be necessary to protect IP generated by the research units in order to allow for easier spin-off generation.

VIABILITY

Governance

The future governance is in flux. Effects are to be evaluated adaptively, as already mentioned.

Future strategy

The future strategy of EE at UT is determined partly by the Institutes as well as by the research groups themselves. Some of the research groups have an internal system *(heidagen)* to set up roadmaps, which the Committee considers a good-practice that other groups may want to follow. There is an inherent danger for the policies of the research groups and the Institutes to drift apart, unless action is taken to regularly foster the dialogue. This is a process that should ensure dynamism and progress, but it should also be groomed carefully since the participants may have important but divergent interests. The Board of the Faculty has a crucial role to play to mitigate the potential conflicts of interests between these largely independent parties.

Focusing and reorganisation in 2014 have produced an unavoidable disturbance. Since then the new strategy has produced good results. This strategy should be continued. The Committee thinks the main thrust of *multidisciplinary technological development* at UT is extremely valuable. Also, the Committee applauds the fact that EE is “teaming up” with for example the polytechnic Saxion, that really complements EE research at another TRL-level.

The strategy with respect to patents and spin-offs has to be more clear and specific goals should be put in place that are clear for all the involved players. From the visit, it was suggested that there is no strong focus any more on the number of spin-offs and also the value of patents owned by the university was questioned. No strong evidence was supporting this vision.

Funding

The funding ratio 1st/ 2nd/ 3rd money stream in 2016 is 47/24/29, and the absolute value of the 3rd money stream has been halved over the evaluation period, showing a negative trend and a relatively low number for industrial work. If the total budget is taken, this ratio even becomes about 67/14/19. Given the focus of EE you would expect more contract research.

RECOMMENDATION: research groups and Institutes might reconsider their position with respect to contract research (see an earlier remark on this matter).

Leadership

EE at UT shows excellent leadership by a few persons; the overall leadership is strong at present. EE has a strong participation and leadership in both national research programmes and H2020.

RECOMMENDATION: an early evolution (rejuvenation) of the leadership in the research groups could be envisaged, allowing the very strong but aging present leadership to take on more global positions in the organisation.

Staff

Staff rejuvenation will provide new opportunities.

RECOMMENDATION: the present constitution in the permanent staff is largely Dutch (with some notable exceptions). As mentioned elsewhere in this report, there is a large international supply of young, very talented young top scientists at the post-doc level or early in their career. Active hiring in this market could rejuvenate the staff, create a better diversity balance (including a higher proportion of females) and ensure continuous very high scientific quality.

Facilities

EE has excellent facilities. The issue will be to keep them well staffed, up to date and well financed. Special attention to the strategy to be followed is of course necessary. The three Institutes provide excellent access to important segments of modern technology for the local research groups, for national and international cooperation and for industry.

The Committee learned that the old clean room is heavily used by *outside users*, which the Committee applauds.

PhD programmes and Graduate School

The PhD pass rate (<5 years) is about 60%. According to the Committee this should rather be 80%. Mentors and their students should be motivated to finish on time more effectively. A qualifying exam in the first year will be introduced to increase efficiency. The Committee considers it important that PhD students get more assistance from an early day on.

PhDs are generally happy with the Graduate School and the programme they can and have to follow. There is also general happiness with the quality, level of advice and facilities inside and outside UT (via collaborations). Professors are very close to the students, which is in generally very much appreciated by the PhD students.

Some graduating PhDs stated that they have a hard time getting information on possible employment outside the region. The Committee thinks a systematic approach to document and advertise potential positions in the country and even beyond might help to solve this issue, probably at University level (it is not to be expected that young doctors in very advanced fields would find local employment easily).

RECOMMENDATIONS:

- Stringent action by the Faculty to improve on the timely success rate of PhD-candidates, through early monitoring, assistance with thesis production and adequate pressure on thesis advisers;

- The Faculty Board is advised to take action on the future employment situation of graduated PhDs.

RESEARCH INTEGRITY

The ethics and data policies are excellent. Lacking in the report are:

- Publication policy (who is allowed to be author of a paper?);
- Handling of property rights;
- Conflict handling between a staff member and the leadership;
- Propriety of industrial contracts.

RECOMMENDATIONS:

- The Faculty Board is advised to decide on a policy for acceptance of third money stream contracts and contract research, the position of staff and students in them and the corresponding handling of property rights;
- The Committee advises that EE at UT adopts the ethical rules of the IEEE concerning authorship of papers.

DIVERSITY

The proportion of junior to senior staff members is too low. This should be increased. Affirmative action is needed to increase the female to male staff ratio. The actions taken presently by the University and the Faculty are already very good but can be further strengthened.

RECOMMENDATION (see an earlier comment on this as well): as the permanent staff of EE at UT is mostly Dutch and male, and the supply of Dutch women at the top scientific level is presently limited, the Committee advises the UT to go international in its hiring policies, in order to tap the much larger supply of very talented, recently graduated top scientists.

Observations and Remarks concerning the Research Groups

Design & Analysis of Communication Systems (DACS)

- The group has achieved very good scientific results, and in the field of operations security they are world top class. This is illustrated by important prizes and publications in top journals. The combination of modelling and measurements is a clear asset of the group;
- The collaboration with Fraunhofer (FPC) is seen as complementary and very productive, this could open further opportunities for more industry collaborations;
- The research challenges are well formulated and very well aligned with major societal challenges;
- The group contributes substantially to the teaching at Bachelor and Master level;
- PhDs are mostly finished within 5 years.

Services, Cybersecurity and Safety (SCS)

- A small and focused research group with an excellent research track record, as illustrated by international benchmarking experiments. It is very positive that the research group covers the whole chain from sensor design to feature extraction and decision making;
- The research focus is very much in line with societal needs, e.g., illustrated by the strong interaction with government agencies;
- The restructuring (integration of BPR in a new group on Data Science) was clarified and it became clear that this is a strategic and welcome evolution;
- Special attention is required to keep the PhD duration within reasonable limits.

Telecommunication Engineering (TE)

- Research group with an impressive publication track record (per FTE), with publications in top journals and conferences (especially in the EMC field);

- Strong links with Thales are an important asset and give access to unique measurement facilities and problem statements;
- The participation of the group in the new group "Radio Systems" has been explained very clearly and the rational was well motivated. Special attention to the practical rollout and integration of the different sub teams is required (not clear who will be leading);
- In general the PhD duration is well managed.

Computer Architecture for Embedded Systems (CAES)

- CAES works on the development and application of techniques for energy efficient, real-time and reliable embedded systems. Currently, 25 PhDs, 4 Postdocs. CAES is involved in 16 large projects. CAES was leading STARS (34 M€). Spin-offs: about 5 spin-offs over the last six years. QBayLogic is a new spin-off that is founded by Emeritus Professor Smit;
- Future research plan: data is becoming more and more important in distributed, energy management systems (position to be filled with Assistant Prof.). Close cooperation with TUD is on-going in this area. In the area of computer architectures there are 4 vacancies (PhD students). A new group is developed in the area of Radio Systems. Deep learning with application in radar technology will be another research plan for the next decade;
- CAES strongly supports the structure and the role of the Institutes (CTIT). Collaboration with other groups of EE and other Departments is greatly appreciated;
- CAES has a research roadmap that is aligned with the Department and the Faculty. The hiring process of new professors is transparent. The profile of the new professorship is agreed upon with the faculty and all professors prior to the call for candidates is launched. Also, the search Committee has an advisory role and members are invited from TU/e and TUD;
- In the area of smart grids (focus on low-voltage and end-users, energy management and services) an interdisciplinary team of electrical engineers, computer scientists and mathematicians is working on multi-commodity prediction, control and optimization problems. These problems allow for fundamental research in multiple disciplines. In the

area of smart grids CAES cooperates nationally with TUD/ TU/e and internationally with other research groups;

- Conclusion: CAES's mission fits well in the societal vision and strategy of the Department. CAES has been able to grow its research activities through the EE Institutes, in which it cooperates with other groups of UT.

Robotics and Mechatronics (RAM)

- RAM is a large research group on robotics in various fields with 9.4 staff members, 5 postdocs and 35 PhD students (20 internal and 15 external). RAM wants to make a difference (with robots) in healthcare, inspection and maintenance. RAM has close cooperation with BSS, BPR, CAES in signal processing. In addition, close cooperation with computer science and mathematics Department are prevalent. "Physics predicts the future and robotics makes it". Main application areas are healthcare and inspection & service. RAM has produced several patents and some (about 6) spin-offs. Prof. Stramigioli emphasizes working together under one roof;
- Future research: widening applications such as inspection of, for example, wind turbines, continue working on medical robotics, policing drones, etc.;
- The EE Institutes (MIRA and CTIT), in which RAM is involved, helped to broaden the applications area of RAM. Support of coordination and application of EU projects through the Institutes is appreciated. Also, the Institutes provide lab space for new initiatives. Support for patents and new business initiatives;
- Cooperation with TU/e (EPE group) and with several medical departments is on-going. Master students typically come from three master programmes (not only EE);
- Conclusion: in the area robotics for health and inspection (flying robots) RAM has high international visibility. The structure of the EE Domain with its institutes has increased the application portfolio of RAM. RAM profits (for its PhDs) from several master programmes outside EE.

Biomedical Signals and Systems (BSS)

- BSS focuses on sensing and control of human functions (motor, soma sensory cardiac and pulmonary) and e-health technology. The group is active in MIRA and CTIT, in particular with eHealth and smart monitoring programmes. BSS has pioneered e.g., in new e-Health coaching strategies for elderly and COPD patients, smart-glasses based auditory and visual cueing for Parkinson's patients and daily-live motor performance assessment on stroke using minimal textile-integrated sensing;
- The group has 32 PhD researchers (16 external), 1,8 Professors, 3 Associate Profs and 2 Assist Prof.). Collaboration within EE and other faculties (mechanical, medical) is facilitated via the EE Institutes or directly via programmes;
- The EE Institutes give support to approve research action through the ethics Committee, providing grants. The Institute (MIRA) grants 50 k€/year to start new collaborations (seed funding), which is greatly appreciated by BSS;
- BSS has three new *perspectief* programmes that include 7 projects with several universities and industry consortia (providing 50% cash and in-kind);
- Conclusion: the strategy to develop Centres has helped BSS to gain new partnerships with other research groups within UT and other faculties. BSS is a strong contributor in MIRA and other internationally leading institutes in the field of Biomedical Engineering. MIRA also offers a strong integrated collaboration with the medical community, closely linked to the unique Technical Medicine curriculum at UT. The Institutes also connect their research to higher TRL levels, which provides insight to the daily life behaviour of patients.

Nano electronics (NE)

- Group works on highly innovative approaches in 2D and nano-materials and devices;
- Group has early industry support for their explorations, and enjoys a healthy influx of awards and project grants;

- The Nano lab creates an environment for the group to perform its research;
- The group feels the responsibility to provide for continued funding for the Nano lab.

Semiconductor Components and Micro sensors and systems (SC and MSS)

- Group has strong support from industry and delivers major innovations to their industry partners;
- The two groups SC and MSS are happy to have joined forces and see a strengthening of their combined roadmaps in the combination;
- The PI's are happy with their team size and project portfolio; they feel no urge to expand their portfolio and prioritize on staff stability.

Biomedical and Environmental Sensor Systems (BIOS)

- Group with an impressive track record and impressive roadmap;
- The group is actively building its future with young researchers (e.g., VENI);
- The group is very active in expanding its research roadmap, and appears successful in landing the proposals in grants and project awards;
- Equally impressive is the amount of spin-offs that have emerged from this group;
- Group actively drives its PhDs to complete their manuscript in (just over) four years.

Integrated Circuit Design (ICD)

- Impressive track record of innovations in analog and rf; the design concepts have been taken up by global industry and have found their way in many modern electronic solutions;
- The group has attracted multiple design Centres of semiconductor companies in the immediate vicinity of the university; This is changing the local eco-system for the better, resulting in a long-term symbiotic relationship;
- The group is collaborating in multi-disciplinary projects, and is happy to be at the verge of the institute scopes.

APPENDIX A CURRICULA VITAE OF THE COMMITTEE MEMBERS

Prof.dr.ir. Patrick Dewilde, Committee Chair, Emeritus Director of the TUM Institute for Advanced Study, Technical University of Munich, Germany. Patrick Dewilde (EE `66 KULeuven, Lic. Math. `68 and PhD `70 Stanford University) has been a professor in electrical engineering at the Technical University of Delft for 31 years, director of the Delft Institute for Micro-electronics and Submicron Technology for ten years, chairman of the Technology Foundation STW (a major Dutch research funding agency) for eight years and director of the Institute for Advanced Study of the Technische Universität München for five years. His research has focused on mathematical issues related to the design, control and operations of dynamical systems in general and in particular circuits and systems for signal processing. He is an IEEE Fellow, an elected member of the Dutch Academy of Arts and Science, has been elevated to the rank of Knight of the Dutch Lion and is presently a honorary professor both at the Technische Universität München and the Technical University of Wroclaw.

Prof.dr.ir. Piet Demeester, Professor of communication networks Ghent University-imec, Belgium. Professor Demeester is full professor in the Faculty of Engineering and Architecture at Ghent University (UGent). He is director of the IDLab-Department (part of imec and Ghent University / University of Antwerp (www.idlab.ugent.be, www.idlab.technology). IDLab (Internet Technology and Data Science Lab) counts about 250 researchers focussing on optical and wireless communication links, wireless networks, fixed networks, cloud and big data infrastructures, multimedia processing, semantic intelligence, machine learning & data mining, distributed intelligence for IoT. Piet Demeester received an MSc degree in EE from Ghent University (1984). He finished his PhD “Metal Organic Vapor Phase Epitaxy for photonic devices” in 1988 and established a research group in this area working on different material systems (AlGaAs, InGaAsP, GaN). This research was successfully transferred to imec in 2002 and resulted in 12 PhDs and 300 publications in international journals and conference proceedings. In 1992 Piet Demeester started research on communication networks and established the IBCN research group (now merged in IDLab). The group produced about 100 PhDs, 1500 publications in international journals and conference proceedings, 30 international awards and 6 spin-off companies. Miscellaneous: chair of the ERC consolidator panel “PE7–Systems and Communication Engineering” (2013-2015-2017), associate editor of the IEEE JLT and of the IEEE/OSA JOCN, fellow of the IEEE in 2009 for “contributions to optical communication networks and technologies”, ERC Advanced Grant “ATTO: Ultra High Capacity Wireless Networking” (2017 – 2021).

Prof.dr.ir. Rik De Doncker, Director of Institute for Power Electronics and Electrical Drives (ISEA) and the E.ON Energy Research Center, RWTH Aachen University, Germany. Professor De Doncker received his PhD degree in electrical engineering from the KULeuven, Belgium. In 1987, he was appointed Visiting Associate Professor at the University of Wisconsin, Madison, where he lectured and conducted research on high-performance induction motor drives and soft-switching dc-to-dc converters for NASA. In 1988, he was a General Electric Company (GE) Fellow at the microelectronic centre, imec, Leuven, Belgium. He joined the GE Corporate Research and Development Center, Schenectady, NY, in the same year. He led research on drives and high-power soft-switching converters, ranging from 100 kW to 4 MW for aerospace, industrial and traction applications. In November 1994, he joined Silicon Power Corporation (formerly GE-SPCO) as Vice President Technology, developing world’s first medium-voltage static transfer switch. Since Oct. 1996, he is professor at RWTH Aachen University, Germany, where he leads the Institute for Power Electronics and Electrical Drives (ISEA). In Oct. 2006 he was appointed director of the E.ON Energy Research Center at RWTH Aachen University, where he also leads the Institute for Power Generation and Storage Systems. In 2007 he became director of the RWTH CAMPUS Cluster Sustainable Energy and leads the BMBF Flexible Electrical Networks (FEN) Research CAMPUS. He is an IEEE Fellow and was 2005-2006 President of the IEEE Power Electronics Society (PELS). 2007-2013, Dr. De Doncker was member of the Board of the German engineering Society VDE-ETG. He is ex-officio member of the EPE Executive Council. Dr. De Doncker is recipient of the IAS Outstanding Achievements Award and the IEEE Power Engineering Nari Hingorani Custom Power Award (2008). In 2009, he led a VDE/ETG Task Force on Electric Vehicles. In 2010, he became member of the German National Platform for Electromobility. He is the recipient of the 2013 Newell Power Electronics IEEE

Technical Field Award, the highest distinction in this field within IEEE, and the 2014 IEEE PELS Harry A. Owen Outstanding Service Award. 2015 he was awarded Fellow status at RWTH University. In 2016 he became member of the German Academy of Science and Technology (ACATECH). 2017 he became Member of the International Advisory Board of French automotive research institute VEDECOM.

Prof.dr.ir. Heikki Koivo, Emeritus Professor of the Department of Electrical Engineering and Automation, Aalto University, formerly Helsinki University of Technology (HUT), Finland. Professor Koivo received the BSEE degree from Purdue University, the MS degree in Electrical Engineering and the PhD degree in Control Sciences from the University of Minnesota. He has been Adjunct Professor at Kwangju Institute of Science and Technology, South Korea and at Harbin Institute of Technology, China. His research interests include study of complex systems, adaptive and learning control, process control, mechatronics, microrobotics, renewable energy and cyber-physical systems. He has authored over 400 scientific publications. He has been the principal investigator in more than 100 research projects. He has been a member of Editorial Boards of many scientific journals such as Journal of Systems and Control Engineering and International Journal of Adaptive Control and Signal Processing. He has been Associate Editor of IEEE Transactions on Robotics and Automation, Administrative Committee Member of IEEE Robotics and Automation Society and Chair of IEEE Finland Section. He is a Fellow of the Finnish Academy of Technology.

Prof.dr.ir. Robert (Bob) Puers, Professor of Microelectronics and Sensors, KU Leuven, Belgium. Prof Puers received his PhD in 1986 at the Katholieke Universiteit te Leuven. He is a European pioneer in the research on micromachining, MEMS and packaging techniques, mainly for biomedical implantable systems. To this purpose, he installed a dedicated clean room for sensor and electronic packaging technology, that now runs for more than 30 years under his guidance. In 2014, he was appointed the chair of the Leuven Nanocenter (LENA), a new research facility that merges different multidisciplinary teams in an up to date facility for nano- and bio-research. Beside MEMS technology, his work also focusses on low power systems, smart interfaces, inductive power and wireless communication for implants. Devices developed range from bladder and eye pressure monitoring, over instrumented orthopedic implants, to implanted pumps for assisted blood perfusion. Bob Puers is the holder of an ERC advanced grant, focusing on smart implantable monitoring systems. He took major efforts to increase the impact of MEMS and Microsystems in both the international research community as well as in industry. He helped to launch three spin-off companies, ICSense, Zenso and MinDCet. Dr. Puers is also an IEEE and IoP fellow.

Prof.dr.ir. Dominique Schreurs, Professor of Microwave Engineering University of Leuven, Belgium. Dominique M. M.-P. Schreurs received the MSc degree in electronic engineering and PhD degree from the University of Leuven (KU Leuven), Belgium. She is now Full Professor with KU Leuven and Chair of the Leuven Center on Information and Communication Technology (LICT). She has been a Visiting Scientist with Agilent Technologies, ETH Zurich, and the National Institute of Standards and Technology (NIST). Her research interests include the microwave and millimeter-wave characterization and modelling of active devices and bioliquids, as well as system design for wireless telecommunications and biomedical applications. Prof. Schreurs is IEEE Fellow and 2018 President-Elect of the IEEE Microwave Theory and Techniques Society. She served as Chair of the IEEE MTT-S Meetings and Symposia Committee (2017), as Editor-in-Chief of the IEEE Transactions on Microwave Theory and Techniques (2014-2016), and also as MTT-S Distinguished Microwave Lecturer (2012-2014). Prof. Schreurs is also the 2018 President of the ARFTG organization, and the General Chair of the 2007, 2012, and 2018 Spring ARFTG Conferences. D. Schreurs also served as Co-Chair of the European Microwave Conference in 2008.

Dr. ir. Leo Warmerdam, patent strategist at NXP Semiconductors, the Netherlands. Dr. Warmerdam studied Electrical Engineering at the Technical University of Delft (MSc 1980) and did his doctoral research at the University of Twente (PhD 1986). He subsequently joined Philips Semiconductors in the nascent field of high voltage integrated circuits. After several marketing and business management roles, he joined the Philips Research organization as team lead in 2003. From 2006 he integrated the semiconductor research organization in the newly formed NXP, followed by leadership of the design research laboratory. Since 2016 he is the patent strategist for NXP. Warmerdam is representing NXP in the Dutch startup eco-system, and is roadmap driver of the HTSM roadmap Components & Circuits.

APPENDIX B SITE VISIT PROGRAMME

Tuesday December 5th, 2017(Eindhoven)

Time	*Activity*	*Participants*
17.30 – 18.30	Welcome of Committee	Committee + delegation of TU/e EE, Rector / Dean
18.30 – 21.00	Formal Committee kick-off and preparations	Committee (private)

Wednesday December 6th, 2017 (Eindhoven)

Time	*Activity*	*Participants*
8.15 – 8.45	Arrival of Committee and preparations of interviews	Committee (private)
8.45 – 9.45	Presentation and Interview Management Team / Faculty Board	MT + Graduate School + Institutional directors
9.45 – 10.00	Break	Committee (private)
10.00 – 12.00	Parallel Interview of Research Groups + Lab Tour and Posters	See table below
12.00 – 12.45	Lunch with PhD students	PhD students from research groups
12.45 – 13.45	Parallel Interview of Research Groups + Lab Tour and Posters (cont.)	See table below
13.45 – 14.00	Wrap up time	Committee (private)
14.00 – 14.45	Interview Management Team / Faculty Board	MT
14.45 – 15.00	Wrap up time	Committee (private)
15.00 – 16.30	Discussing and writing preliminary judgments	Committee (private)

16.30 – 17.00	First impressions by Committee	MT Programme leaders Invited staff
17.15 – 19.15	Dinner	Committee (private)
19.15	Travel to Delft	

Thursday December 7th, 2017 (Delft)

Time	***Activity***	***Participants***
8.15 – 8.45	Arrival of Committee and preparations of interviews	Committee (private)
8.45 – 9.15	Welcome of Committee by Rector	Rector and dean
9.15 – 10.15	Presentation and Interview Management Team / Faculty Board	MT + Graduate School + Institutional directors
10.15 – 10.30	Break	Committee (private)
10.30 – 12.30	Parallel Interview of Research Groups + Lab Tour and Posters	See table below
12.30 – 13.15	Lunch with PhD students	PhD students from research groups
13.15 – 15.15	Parallel Interview of Research Groups + Lab Tour and Posters (cont.)	See table below
15.15 – 15.30	Wrap-up time	Committee (private)
15.30 – 16.15	Interview Management Team / Faculty Board	MT
16.15 – 17.30	Discussing and writing preliminary judgments	Committee (private)
17.30 – 18.00	First impressions by Committee	MT Programme leaders Invited staff
18.15 – 19.45	Dinner	Committee (private)
19.45	Travel to Twente	

Friday December 8th, 2017 (Enschede)

Time	***Activity***	***Participants***
8.15 – 8.45	Arrival of Committee and preparations of interviews	Committee (private)
8.45 – 9.15	Welcome of Committee by Rector	Rector and dean
9.15 – 10.15	Presentation and Interview Management Team / Faculty Board	MT + Graduate School + Institutional directors
10.15 – 10.30	Break	Committee (private)
10.30 – 12.30	Parallel Interview of Research Groups + Lab Tour and Posters	See table below
12.30 – 13.15	Lunch with PhD students	PhD students from research groups
13.15 – 15.15	Parallel Interview of Research Groups + Lab Tour and Posters (cont.)	See table below
15.15 – 15.30	Wrap-up time	Committee (private)
15.30 – 16.15	Interview Management Team / Faculty Board	
16.15 – 17.30	Discussing and writing preliminary judgments	Committee (private)
17.30 – 18.00	First impressions by Committee	MT Programme leaders Invited staff
18.00 – 18.10	Feedback EE TU/e, TUD, UT	MT of three Faculty's
18.10 – 18.30	Refreshments	All invited
18.30	Closure	

Parallel Interview Research Groups + Lab Tour

Eindhoven 10.00 – 13.45

	Parallel interview I **De Doncker, Koivo**	**Parallel interview II** **Puers, Warmerdam**	**Parallel interview III** **Demeester, Schreurs**
10.00-11.00	EES	MSM	EM
11.00-12.00	EPE	PHI	ECO
12.00-12.45	Lunch		
12.45-13.45	CS	ES	SPS

Delft 10.30 – 15.15

	Parallel interview I **De Doncker, Koivo**	**Parallel interview II** **Puers, Warmerdam**	**Parallel interview III** **Demeester, Schreurs**
10.30-11.30	DCE&S	BE	MS3
11.30-12.30	IEPG	ECTM	TS
12.30-13.15	Lunch		
13.15-14.15	PVMD	EI	CAS
14.15-15.15		ERL	QE

Twente 10.30 – 15.15

	Parallel interview I **De Doncker, Koivo**	**Parallel interview II** **Puers, Warmerdam**	**Parallel interview III** **Demeester, Schreurs**
10.30-11.30	RAM	NE	DACS
11.30-12.30	CAES	BIOS	TE
12.30-13.15	Lunch		
13.15-14.15	BSS	SC/MSS	SCS
14.15-15.15		ICD	

APPENDIX C ABBREVIATIONS OF RESEARCH GROUPS

TUD	
BE	BioElectronics
CAS	Circuits and Systems
DCE&S	DC Systems, Energy Conversion & Storage
ECTM	Electronic Components, Technology and Materials
EI	Electronic Instrumentation
ELCA	Electronics Research Laboratory
IEPG	Intelligent Electrical Power Grids
MS3	Microwave Sensing, Signals and Systems
PVMD	Photovoltaic Materials and Devices
QE	Quantum Engineering
TS	Terahertz Sensing
TU/e	
CS	Control Systems
ECO	Electro-Optical Communications
EES	Electrical Energy Systems
EM	Electromagnetics
EPE	Electromechanics and Power Electronics
ES	Electronic Systems
MSM	Mixed-signal Microelectronics
PHI	Photonic Integration
SPS	Signal Processing Systems
UT	
BIOS	Biomedical and Environmental Sensor Systems
BSS	Biomedical Signals and Systems
CAES	Computer Architecture for Embedded Systems
DACS	Design and Analysis of Communication Systems
ICD	Integrated Circuit Design
MSS	Micro sensors and systems
NE	Nano electronics
RAM	Robotics and Mechatronics
SCS	Services, Cybersecurity and Safety
SC	Semiconductor Components
TE	Telecommunication Engineering

APPENDIX D EXPLANATION OF THE SEP CRITERIA

Research quality is seen as the contribution that research makes to the body of scientific knowledge. The scale of the unit's research results (scientific publications, instruments and infrastructure developed by the unit, and other contributions to science) are also assessed.

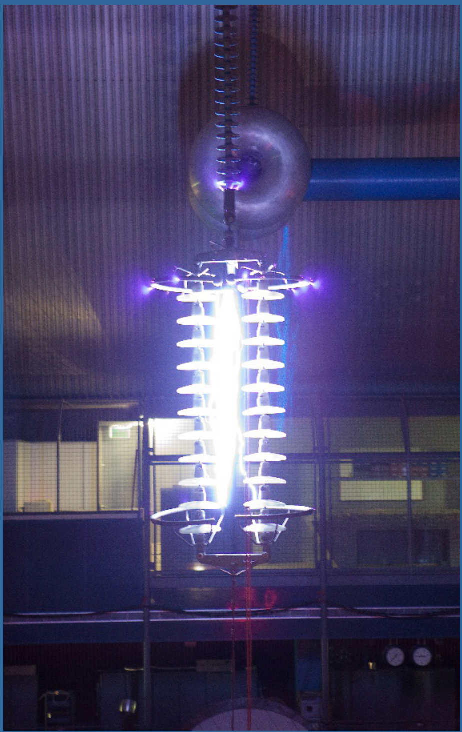
Relevance to society is seen as the quality, scale and relevance of contributions targeting specific economic, social or cultural target groups, of advisory reports for policy, of contributions to public debates, and so on. The point is to assess contributions in areas that the research unit has itself designated as target areas.

Viability is seen as the strategy that the research unit intends to pursue in the years ahead and the extent to which it is capable of meeting its targets in research and society during this period. It also considers the governance and leadership skills of the research unit's management.

Appendix E Meaning of key wording as used by the Committee in this report

Centre	Grouped research activities within a TU that cross the boundaries of single research groups and address a multidisciplinary topic cooperatively
Department	Organisational and administrative clustering of research groups
Domain of EE	The grouped EE research activities within each TU
GS	Graduate School
Institute	A largely autonomous research institution that concentrates a substantial outlay of means in a well-defined technological field
Institution	Any clearly defined organisation
IP	Intellectual Property
Laboratory	Physical space where research (experiments) take place
Money streams	1st money stream: direct funding by the University, obtained directly from the Government, and financial compensation for educational efforts. 2nd money stream: research funding obtained in national and international scientific competition (e.g., grants from NWO, KNAW, EU/ERC, ESF). 3rd money stream: research contracts for specific research projects obtained from external organisations, such as industry, government ministries, the European Commission, and charity organisations
Research group	Group of researchers who perform research in a specific field, and form an administrative unit (a.k.a section)
Researcher	Scientific staff, postdoc and PhD-candidate

Scientific staff	(Assistant, associate and full) professors. *Junior* staff correspond to recently appointed but graduated research staff members at the beginning of their career (first six years of employment)
TRL	Technology Readiness Level



Quicken ORGANISATIE ADVISEURS

bureau voor organisatieontwikkeling