Self-Evaluation Report 2017-2022

Civil Engineering

TU Delft

Colophon

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Design
Haagsblauw, Den Haag

Information
TU Delft
Faculty of Civil Engineering and Geosciences
Stevinweg 1
2628 CN Delft
+ 31 15 27 89802
www.tudelft.nl/citg

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Content

Preface

Many people were involved in drawing up this self-evaluation report. Unlike previous reports, which were often written by a small number of senior academics, we explicitly chose to involve a broad selection of representatives from each of the five Civil Engineering departments this time. Each department established a writing team, typically consisting of three to five staff members, including Assistant and Associate Professors. Moreover, the departments organised various input and review sessions, to ensure broad-based representation. To align and harmonise these efforts, we also appointed a Planning, Coordination, and Strategy Alignment committee (PCSA), composed of three enthusiastic Assistant and Associate Professors and two faculty support staff members, which effectively managed the process of compiling the self-evaluation report. The final responsibility for the content of the report rests with the five Department Chairs and the Dean.

Regarding the structure of the document, we chose to address the topics of Human Resources, Open Science, Academic Culture, and PhD Policy and Training in stand-alone chapters that highlight faculty-wide policy to avoid repetition in the individual department chapters. Department-specific implementations of these policies are discussed in the individual department chapters.

I would like to thank all contributors to this report, with a special mention to the members of the PCSA: Branko Šavija, Monique Waale, Shadi Sharif Azadeh, Stijn van Boxmeer, and Ton van den Bremer.

Jan Dirk Jansen, Dean of the Faculty of Civil Engineering and Geosciences.


NATURAL, LIVING AND BUILT ENVIRONMENT
TU Delft
ENVIRON-MENTAL ENGINEERING
CIVIL ENGINEERING
APPLIED EARTH SCIENCES
ENERGY TRANSITION
RESOURCE AVAILABILITY
CLIMATE CHANGE
URBANISATION
MOBILITY
CLEAN WATER
WATER
EARTH SYSTEM
NATURAL RESOURCES
STRUCTURES
INFRASTRUCTURE
MATERIALS
UNDERSTAND • INTERVENE • IMPROVE

1. Faculty of Civil Engineering and Geosciences

1.1 Introduction

1.1.1 Introduction to TU Delft

TU Delft (Delft University of Technology) was founded in 1842 as a royal academy for the education of civil engineers. It has since grown into a university with eight faculties, around 28,000 students and 3,700 academic staff members. TU Delft's vision is as follows: *Delft University of Technology contributes to solving global challenges by educating new generations of socially responsible engineers and expanding the frontiers of the engineering science.*

This led to the following mission:

- We perform world-class research by combining science, engineering and design in a socially responsible manner. Thus, we advance and share the benefits of technology.
- We develop and enhance the expertise of tomorrow's engineering leaders and educate professional, high-level and responsible engineers throughout their careers.
- We help develop and deliver technology-driven, innovative solutions to societal problems through collaborations with leading national and international partners whilst being firmly rooted in Delft.
- We continuously improve our collective effectiveness, performance and organisational resilience through the principles and practice of professionalism, collaboration and openness.

To explain the nature of research carried out at TU Delft, we use a classification in two dimensions as shown in Figure 1.

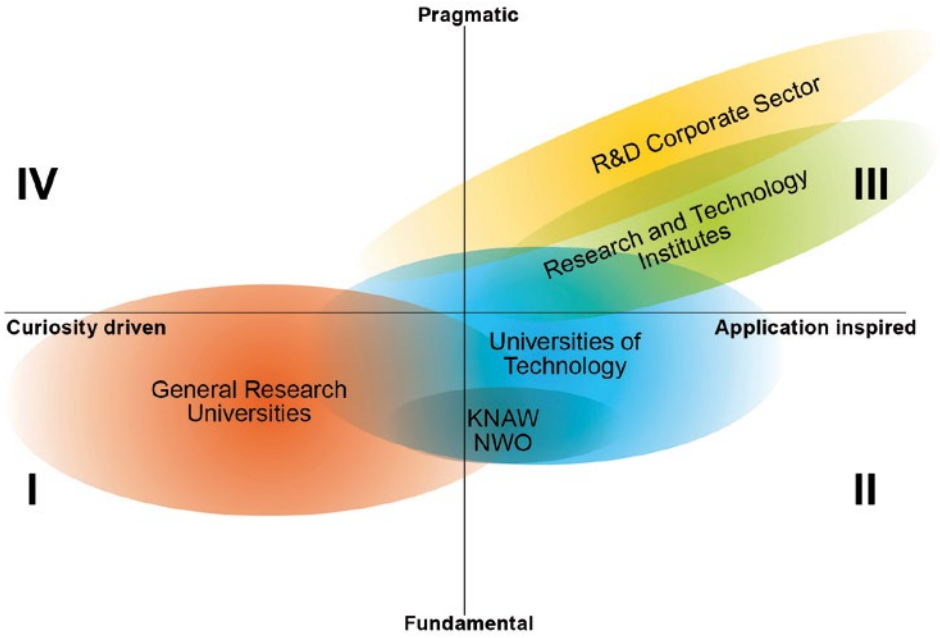


Figure 1 Two-dimensional field describing the nature of research (from TU Delft roadmap 2020).

The first dimension concerns the motivation of the research activities, which may range from curiosity-driven to application-inspired, as indicated on the horizontal axis. The second dimension concerns the nature of the research activities, which may range from fundamental to pragmatic as indicated on the vertical axis. General research universities and universities of technology are both primarily concerned with fundamental research. The difference between these two types of universities lies in the motivation for their research, namely curiosity-driven or application-inspired. Universities of technology share the application-inspired motivation with large research and technology institutes (so-called TO2s, such as TNO, Deltares or KNMI) or R&D departments of the corporate sector. Their research differs, however, in the nature of the respective research activities. Whereas universities of technology such as TU Delft carry out (application-inspired) fundamental research, technological institutes and industry are mainly engaged in more pragmatic and short-term oriented research, targeting solutions for the challenges of today and tomorrow, while universities focus on challenges of the future. The common motivation to tackle societal and technological needs, inspired by applications, forms the basis of our cooperation with industry. The difference in the nature of research is reflected in the structure of many of our collaborative research contracts. Fundamental research questions are addressed in PhD and postdoc research projects, whereas more pragmatic research questions and implementation aspects are addressed by research staff from our partners at TO2s or in industry.

TU Delft consists of eight discipline-oriented faculties, while interdisciplinary activities can be developed on a broader scale either in interfaculty research institutes, in university-wide research-based initiatives (Delft Research Initiatives: DRIs) or in national and international programmes (Figure 2).

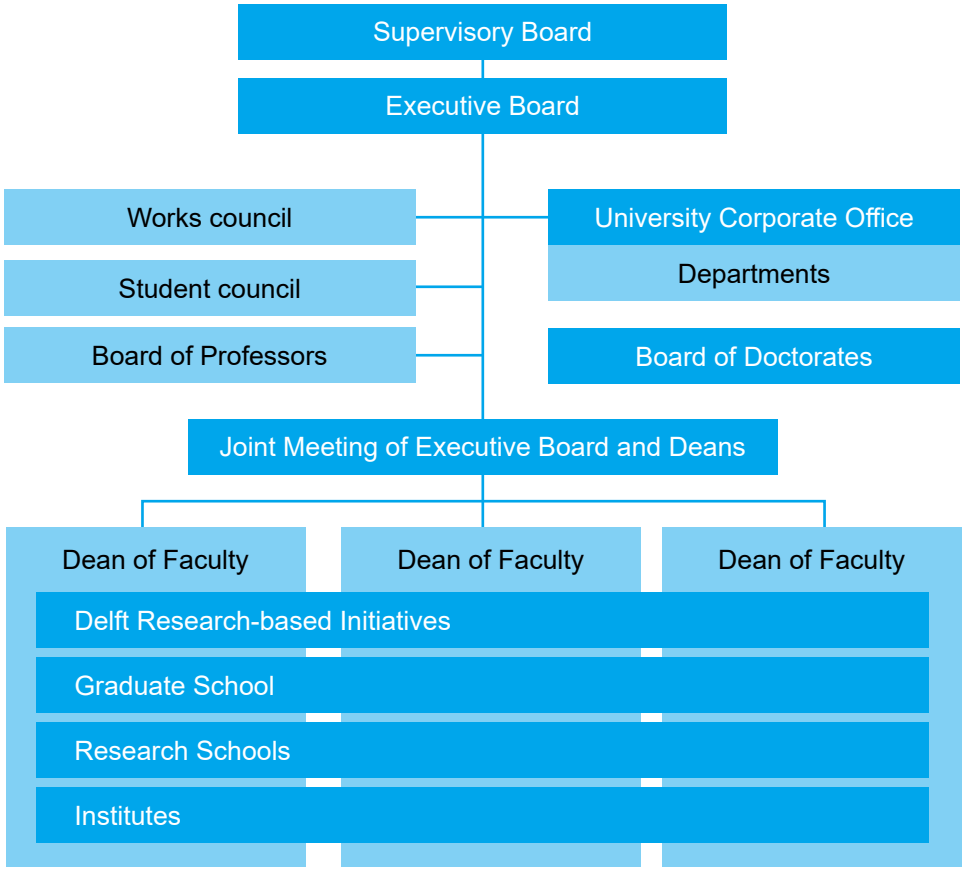


Figure 2 Main organisation of Delft University of Technology.

1.1.2 Introduction to the Faculty of Civil Engineering and Geosciences

The Faculty of Civil Engineering and Geosciences (Faculty) has a major impact on the world stage through its research, which is internationally recognised by many institutions (see Figure 3): TU Delft is ranked 2nd in the Civil and Structural Engineering category of the 2022 QS World University Ranking by subject; it is also ranked 2nd in Transportation and 9th in Water Resources, to a large extent due to results obtained by the Faculty.

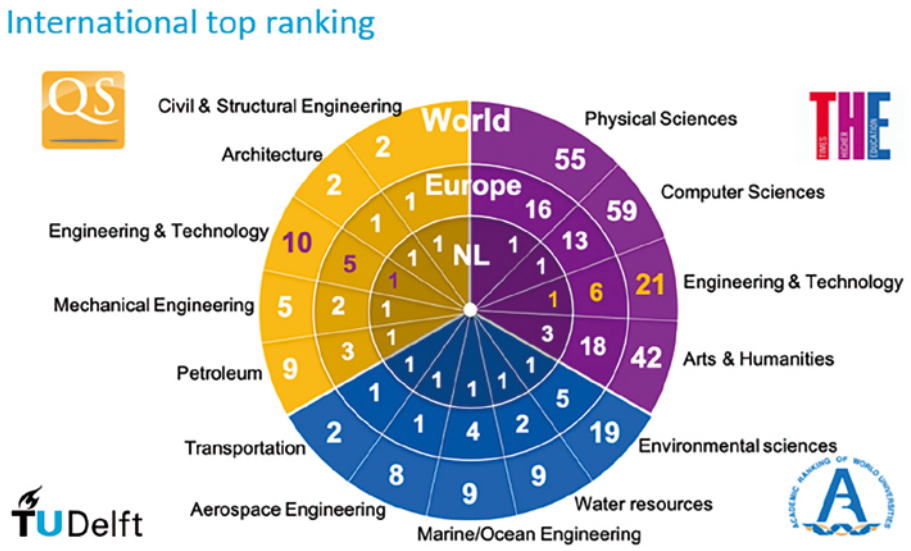


Figure 3 TU Delft in world university rankings.

Prof.dr.ir. Jan Dirk Jansen has been Dean of the Faculty of Civil Engineering and Geosciences since May 1st 2018. He has overall responsibility for research, education, valorisation and management. The Faculty consists of seven departments: two in geoscience (reviewed in 2021) and five in civil engineering; the latter of which is comprised of:

- Engineering Structures (ES);
- Materials, Mechanics, Management & Design (3MD);
- Hydraulic Engineering (HE);
- Water Management (WM);
- Transport & Planning (TP).

The Dean, the seven departmental chairs and the director of education form the Faculty management team (MT), which is responsible for the strategic decisions about research directions and major developments in educational and valorisation processes. The executive secretary of the Faculty and the HR and Finance managers also participate in MT meetings to guarantee a direct link to the execution of the decisions. The Faculty regulations describe the governance and operations of the Faculty. Figure 4 provides a visual representation of the Faculty's governance.

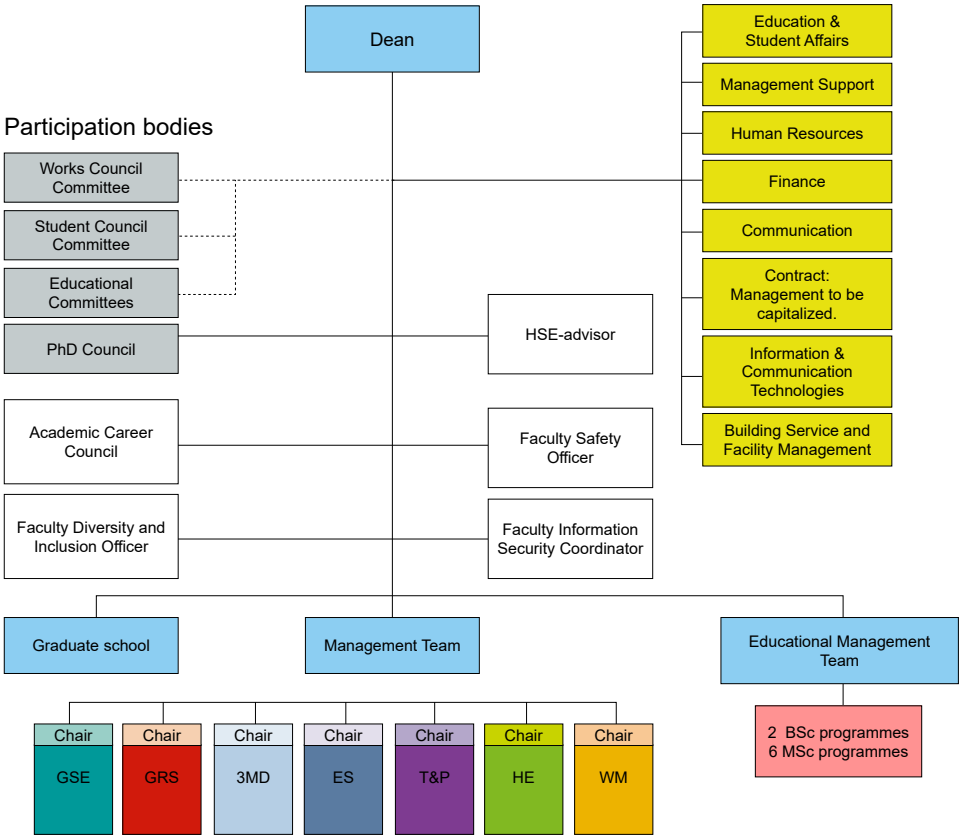


Figure 4 Organogram Faculty of Civil Engineering and Geosciences.

The director of education and six directors of studies form the educational management team (EMT) and are responsible for all educational matters for the two BSc programmes Civiele Techniek (*Civil Engineering*, taught in Dutch) and Applied Earth Sciences (taught in English); the three in-house MSc programmes (all taught in English) Civil Engineering (CE), Applied Earth Sciences (AES) and Environmental Engineering (EnvEng); the two cross-faculty programmes of Transport, Infrastructure & Logistics (TIL, jointly with Mechanical Engineering (ME) and Transport Policy and Management (TPM)) and Construction Management & Engineering (CME, jointly with Architecture and the Built Environment (ABE) and TPM); and the cross-university programme of Applied Geophysics and Petrophysics (AGP, jointly with ETH Zürich and RWTH Aachen).

The support staff are divided into eight departments: Education & Student Affairs, Management Support, Human Resources, Finance, Communication, Contract Management, Information & Communication Technologies (ICT), and Building Services & Facility Management.
Participation of employees and students is organised through an elected Works Council (employees) and the Faculty Student Council. The councils periodically meet separately with the Dean to discuss policy matters.

The Faculty also has a director of the Graduate School (see chapter 3) and a Faculty Diversity & Inclusion (D&I) Officer (see chapter 4). The Faculty D&I Officer has a broad role to serve as an ambassador and advisor to the MT for all matters concerning Diversity and Inclusion. Moreover, the Faculty is supported by a Faculty Information Coordinator (FIC) and three advisors related to physical safety and IT security: a Health, Safety & Environment (HSE) advisor, a Faculty Safety Officer (FSO) and a Faculty Information Security Coordinator (FISC). The HSE advisor and the FSO focus on the policy and execution of physical safety in the laboratories and during experiments and fieldwork; the FISC focuses on IT awareness, design and compliance with IT security measures. PhD candidates are represented through a self-organised PhD council and have periodic meetings with the Dean and the director of the Graduate School.

Facilities to support research in the Faculty include an extensive and unique laboratory infrastructure that enables the Faculty to perform experimental research across a wide range of scales and on a wide variety of topics (from large-scale mechanical testing to research on biohazardous sludges), computers and datacentres for modelling & simulation, and equipment such as drones, jet skis and cars for field measurements. The Faculty also conducts experiments in real-life settings.

The facilities are mostly in-house labs and, in many cases, unique. Laboratories and their support staff are typically organised at the departmental level rather than at the level of sections or individual researchers. Examples of large field experiments are the mud engine (IJsselmeer), the sand engine (North Sea) and research in estuaries (Zeeland, Wadden) along rivers, monitoring traffic flow or the behaviour of infrastructure. In this review period, the shift towards virtual and real-life settings has developed further, although (field) labs remain essential for validating numerical simulations. Examples of participation in living labs are the Amsterdam-based Advanced Metropolitan Solutions[1] and the field labs of the Valorisation Programme Delta[2].

This chapter has been prepared by the Dean and the executive secretary of the Faculty with input from relevant support staff.

1.2 Mission and strategic aims of the past six years

1.2.1 Mission

In 2018, the Faculty's management team decided to review and update the Faculty Strategy to define where it should be in 2024. The purpose was to enable and guide all departments and their personnel in necessary decisions regarding research priorities, the educational programme and the budget within the overall TU Delft Strategic Framework. The Faculty strategy should provide shared boundary conditions for the organisation and provide a basis for the next Civil Engineering and Geosciences research evaluation cycles. In this section, we focus on the current Faculty strategy, which covers 2019-2024.

[1] How can historic quay walls in Amsterdam become future-proof? (https://www.ams-institute.org/urban-challenges/resilient-cities/how-can-historic-quay-walls-amsterdam-become-future-proof/)
[2] Proeftuinen - VPdelta (tudelftcampus.nl) (https://vpdelta.tudelftcampus.nl/proeftuinen/)

The Faculty's mission is: *To create a better living environment for society*; and its motto is: *To understand, to intervene, to improve*. Figure 5 displays the Faculty's mission, motto and strategy in a nutshell.

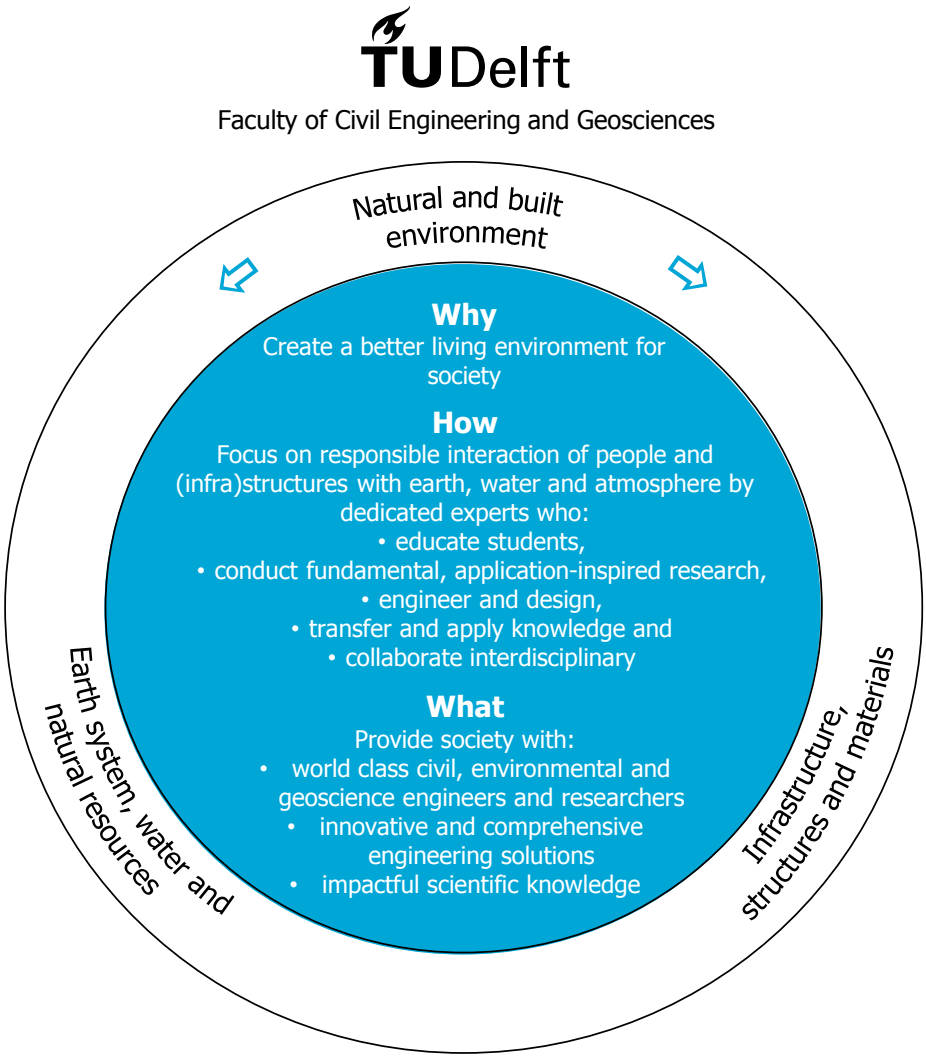


Figure 5 Faculty Strategy 2019-2024.

1.2.2 Strategic aims

The Faculty's departments have all proven to be successful at education and research in their own disciplines. This is not only evident from previous assessments but also in the resulting strong position of the Faculty in this regard. However, to make an impact in a world that is highly subject to change, the Faculty must find a balance between responding to current and future developments in society and maintaining the strengths of its core disciplines. We want to emphasise that during the process of developing the Faculty's strategy, the involvement of the staff and students was important for the process as well as the result. To make sure the defined strategy truly reflects the shared vision and goals of (especially early-career) academic staff, we ensured their participation in the project team, which consisted, by design, mostly of (Academic Career Track) Assistant and recently promoted Associate Professors. The project team delivered and communicated the strategy document, liaised with the departments and managed dependencies. Research staff comprised of Assistant, Associate and Full Professors, and permanent researchers (formally, this category also includes lecturers) were involved in the strategy development process on a voluntary basis by participating in so-called walk-in sessions. Furthermore, junior research staff (including postdocs and PhD candidates), support staff and student councils participated through a review process. Final decisions were made by the Faculty MT.

CEG strategy 2019-2024

Student and Education

Ambitions 2024
To educate students to become and remain world class civil, environmental and geoscience engineers who:
- have in-depth knowledge in and understanding of core disciplines
- are competent to work in data rich yet uncertain environments
- come up with innovative and integrated engineering solutions
- can convince stakeholders for evidence-based decision making
- can work and collaborate in an interdisciplinary and multi-cultural environment
- act in society as responsible engineers

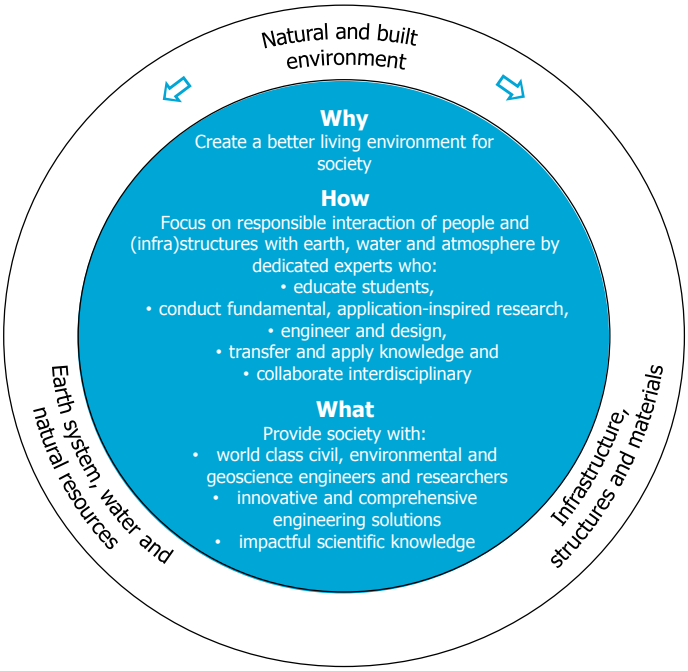
To be the institute of choice for students and teachers. CEG has:
- best courses: inspiring teachers and methods, synergy between fundamental and application-driven, lab and field teaching, high face-to-face contact between teacher and student and excellent online self study possibilities
- an excellent reputation on education
- up-to-date and coherent tracks based on broad civil, environmental and geoscience engineering knowledge
- up-to-date laboratories
- healthy student - staff ratio
- balanced teaching load

People and Community

Ambitions 2024
To be the employer of choice for all staff. CEG:
- has a stimulating intellectual environment
- provides opportunities comparable to other renowned universities
- promotes and practices diversity
- develops leadership capabilities in its scientific staff
- offers transparent and flexible career paths
- assesses and rewards both individual and team performance
- feels responsible for a healthy work-life balance
- focuses on a good team spirit
- ensures a fair distribution of workload

To have an active and connected science, staff and alumni community based on:
- common interests
- shared values

TU Delft
Faculty of Civil Engineering and Geosciences



This doublesided Onepager contains the Strategy 2019-2024 for the Faculty of Civil Engineering & Geosciences. The formulated strategy is based on the TU Delft Strategic Framework 2018-2024 *Impact for a better society*. This document is still a draft version and is for internal and own use only. Lay-out will be changed during April 2019. The final version of this document will be translated into the Dutch language.

Research and Innovation

Ambitions 2024
To conduct world class fundamental application-inspired research that supports the responsible interaction of people and (infra)structures with earth, water and atmosphere. CEG has:
- a strong link between education, science, engineering and design
- strong mono-disciplines and coherent interdisciplinary research themes
- researchers who are able to work and collaborate in an interdisciplinary and multi-cultural environment
- a strong focus on new research techniques
- flexibility to adopt new research topics
- an open science approach

To be the institute of choice for researchers. CEG:
- is a recognized research authority by society and scientific peers
- has a proven track record on transferred and applied knowledge to society
- is proactive in identifying and responding to societal needs
- has highest standards for scientific integrity
- values individual and collective output
- aims for outstanding research facilities, funding and support
- works in excellent teams that cover research, acquisition of funding, valorization and support
- involves stakeholders from public and private domains
- has high visibility at industry, government and funding agencies

Campus and Services

Ambitions 2024
Our building is the place to be for students, academic and support staff. CEG's faculty building:
- meets high health, safety and environment (HSE) standards
- fulfills diverse workspace needs
- has appropriate computing, teaching and lab facilities
- is a showcase of our world-class expertise and ambitions
- stimulates co-operation, personal growth, creativity and productivity

To have excellent and efficient support services that are fully aligned with academic and educational staff's needs

Figure 6 Faculty Strategy Two-Pager 2019-2024 (general).

Student and Education

Change themes 2019-2024	Strategic choices 2019-2024
Curriculum structure and content	1. Give core disciplines a structural place throughout broad BSc programs as a basis for advanced specialization in the various master programs 2. Challenge the status quo of existing BSc and MSc programs and tracks and decide on and implement necessary improvements in line with CEG mission statement 3. Give emerging technologies and societal challenges a recognizable role in both BSc and MSc programs 4. Oblige interdisciplinary education in MSc linked to long-term cross-department research themes
Environment for education to grow	1. Enhance skill-based knowledge like academic writing, presentation and programming 2. Improve educational facilities (i.e. instruction rooms, e-learning facilities, computing) and educator support 3. Create extra-curricular showcase projects for students to participate in (CEG dream teams)
Distribution of teaching load	1. Distribute teaching load more evenly over departments and individuals 2. Increase the number of lecturers per BSc course with specific in-depth knowledge on course aspects involved 3. Distribute student influx more evenly over the MSc-tracks
Education and promotion culture and efficiency	1. 80% of students who have passed their BSA finish their BSc within 4 years 2. 90% of PhD candidates who have passed their go/no-go obtain their degree within 5 years.

Research and Innovation

Change themes 2019-2024	Strategic choices 2019-2024
Societal challenges and faculty research themes	1. Departments focus on and align activities with the key societal challenges for CEG: a. Availability of clean water b. Climate change c. Transition to renewable energy systems d. Resource depletion e. Urbanization 2. Set the societal agenda through mapping and involving of stakeholders aimed on the key societal challenges for CEG
Environment for research to grow	1. Maintain strengths in following disciplines: a. Fluid and sediment dynamics b. Physics of materials c. Earth sciences d. Mechanics of solids and structures e. Transport network and system sciences 2. Develop cross-department methods and technologies: a. Monitoring, sensing and data b. Numerical modeling, simulation and design c. Risk analysis, uncertainty quantification, probabilistic design d. Smart materials and structures 3. Realize integrated use of experimental lab facilities of the faculty

People and Community

Change themes 2019-2024	Strategic choices 2019-2024
Appreciation of group and individual	1. Appreciate in R&O and VLC also individual contributions to: a. the group output and responsibilities b. establishment and maintenance of external relations for education, research and valorisation c. societal impact and outreach 2. Change VLC norms to be tailored to individual talents: Faculty members should be excellent on at least one criterion and competitive on other criteria 3. Align R&O with VLC expectations and recommendations
Environment for individuals to grow	1. Develop staff actively and based on transparent HR policy on recruitment, guidance, training, promotion and outplacement 2. Reward initiatives and responsibilities taken by individuals to get the best out of themselves and out of others 3. Integrate every Faculty members' actual personal mission statement and personal development plan in R&O cycle 4. Initiate a VLC track for the career development of lecturers
Inclusiveness	1. Increase the number of female Faculty members (UD, UHD, HL) and lecturers to be a representation of the PhD population 2. Represent at least 1 junior staff i.e. 'young' U(H)D in each department MT 3. Apply zero tolerance on prejudices, gossiping and intimidation

Campus and Services

Change themes 2019-2024	Strategic choices 2019-2024
Health, safety and environment (HSE)	1. Create an environment to have zero incidents[2]: a. Staff at all levels take own responsibility in behaviour b. Clear organization, policy and procedures c. Implement structural HSE measures d. Have 100% coverage of safety reports for experiments e. Use dedicated HSE software routinely for registration and monitoring f. Publish safety performance
Co-ownership	1. Ensure sufficient (quantity and quality) project and financial support staff to departments 2. Make distribution of responsibilities between academic staff and support staff fully clear and complied with 3. Make the degree of academic and educational staff's satisfaction a criterion in support staff's R&O and vice-versa
Building and workspace	1. Aim for mid-term renovation with attention for: a. Improved spatial lay-out including more small meeting rooms b. Up-to-date interior design c. Improved climate control 2. Practice sustainability throughout the building including the restaurant

Figure 7 Faculty Strategy Two-Pager 2019-2024 (detailed).

The outcome of the process was captured in the form of a two-pager. The first page was the basis for our strategy and divided our strategic aims into four specific categories (Figure 6). The strategy for these four categories is described in more detail on the second page (Figure 7).

Following the TU Delft Strategic Framework, the four categories of strategic aims at Faculty level are:
1. Student and Education;
2. Research and Innovation;
3. People and Community;
4. Campus and Services.

At departmental and Faculty levels, these categories have been specified more in-depth with detailed aims. Departments follow this strategy, and at Faculty level we have set specific priorities aligned with the strategy. Triggered by the results of two educational reviews of the Applied Earth Sciences (AES) and Civil Engineering (CE) BSc and MSc programmes, the Faculty chose to prioritise the redesign of its educational programmes such that it became the major element of the strategy implementation process over the past period.

1.3 Recommendations of previous assessment and follow-up

This section describes how we have addressed the recommendations from the previous research assessment.

→ **Availability of high-performance computing facilities**
The committee gave the advice to invest in high-performance computing. The Faculty played an active role in the realisation of the TU Delft high-performance computing cluster (DelftBlue[3]). This is a heterogeneous computing cluster for the whole university, consisting of the newest computing and data nodes (partner Fujitsu, approx. 30,000 cores, operational since June 2022). DelftBlue facilitates scientific breakthroughs in large-scale, complex civil engineering issues, for example in the fields of environmental flows, reservoir simulation, multi-modal transport and multi-scale material mechanics. DelftBlue is also used for the training of our BSc, MSc and PhD-students by means of advanced courses on massive parallel computing.

→ **Findability of staff on the internet**
The committee found it difficult to find the Faculty on the website and noticed that multiple formats were used. TU Delft and the Faculty have taken up the task to work on a more uniform way of representing its staff online. Uniform TU Delft staff pages were introduced in 2021, which can be created by staff members themselves, including links to their educational tasks, research output, ancillary activities and media coverage. At this moment, around 70% of Faculty staff have generated such a page. The profiling of staff members has also been improved by adding Stories of Science about their research to their personal page. Staff members can more easily be localised on the website through the staff item in the top menu bar on the website, which is now identical for all departments. Most departments show their staff in academic categories (PhD candidates, postdocs, researchers, staff members), and certain departments also show their staff members at section level or research lab level, as is the case for the Transport and Planning department. The departmental websites differ in the level of detail displayed but are all built around the same basic menu of topics.

[3] https://www.tudelft.nl/dhpc/system

→ **Total amount and source of funding**
The committee was concerned about an imbalance between the different funding sources. Over the years, the total funding of the Faculty remained stable (see Appendix B.2). The positive effect on the direct funding due to the Sectorplan and the Van Rijn scheme (see section 1.4.3) is evident as of 2021. We expect that research grants and contract research will rise in line with the increase in direct funding over time, as additional staff funded by the Sectorplan and the Van Rijn scheme will also apply for grants from these sources. Research is primarily financed through the funding agencies within the Netherlands (listed as Research Grants) and the European Union (H2020/Horizon Europe, somewhat confusingly listed as Contract Research). The Contract Research category therefore comprises funding from the European Union and industry. Almost 30% of our PhD research is executed by PhD candidates on bursaries and is not visible as such in the funding table (see Appendix B.2), as these bursaries are paid directly to the PhD candidates. Until 2019 no direct funding was available for PhD or postdoc research. Additional governmental budget from the Sectorplan and the Van Rijn scheme allowed us to hire respectively 16 new Academic Career Track staff members in 2019 and 10 in 2020, and the availability to review this policy. From 2019, we have provided all new Assistant Professors, including those not funded by the above schemes, with a directly funded PhD candidate and new Associate Professors with a 210k€ start-up package.

→ **Sharpen strategic and integral thinking on societal impact & incorporating societal relevance within strategy and operations**
The committee identified that societal relevance influenced our work but addressed the need to better incorporate societal relevance into our strategy and operations. In section 1.2.2, we explain how societal relevance has been incorporated within the strategy review and strategic aims.

→ **Connections to universities of applied science**
The committee expected fruitful collaborations with universities of applied science. In the past, the relationship between TU Delft and the universities of applied science was mainly defined by graduates of the universities of applied science starting their MSc degrees. Funding agencies have since created research programmes especially for universities of applied science, which offer possibilities for collaboration. Existing connections have been realised bottom-up. Scientists start projects based on content and their complementary qualities. However, the Faculty has not directed major efforts on structurally improving our connections with universities of applied science and we will likely have to increase our activity level in the upcoming period.

→ **Strengthen connection with sector transport and infrastructure**
The committee identified a gap in our connection with the outside world related to the field of transport and infrastructure. We have appointed a Construction & Infrastructure programme director tasked with developing account management with key accounts in cooperation with the TU Delft Innovation & Impact Centre (I&IC), thus strengthening TU Delft's role within transition tasks in the sector and strengthening our position in various networks. The recruitment of a second Faculty valorisation officer (business developer CiTG) has started. The focus for this vacancy is on support for research funding opportunities and strengthening relationships with partners, in close cooperation with I&IC.

→ **Cross-departmental collaboration**
The committee expected more collaboration between the fields within the Faculty. The Faculty has primarily promoted cross-departmental collaboration through its review of the MSc programmes, in particular through the introduction of team-based teaching, the Faculty-wide MUDE module and cross-programme modules (see section 1.4.2). This approach led to spin-off in the form of significantly increased awareness of research

activities amongst staff and subsequent cross-departmental collaboration. Moreover, a Faculty-wide call for additional investment in research infrastructure was made in 2021, with cross-departmental collaboration as one of the assessment criteria, and a second call for cross-departmental research positions (at Assistant Professor and postdoc levels) was made in 2022. The first call resulted in a commitment to invest 2.6m€ in additional equipment and facilities for field and laboratory experiments across the five Civil Engineering Departments. The results of the second call will form input for the planned revision of the Faculty strategy (see section 1.5).

1.4 Strategic process of the past six years

1.4.1 General

In this research assessment, we focus on the developments related to the specific aspects and the three assessment criteria at the departmental level (research quality, societal relevance and viability). The strategic aims of the Faculty have been translated into the day-to-day work of departments and the support staff. In the following nine chapters we will elaborate on the strategic aims for the specific aspects and the departments, including evidence of their accomplishments and their future strategies. The outcome of the research assessment will be input for the review of the Faculty strategy, thereby securing the integration of the research assessment's recommendations in the strategic planning.
In this section, we will highlight the developments that have had a considerable impact on the Faculty over the past six years. We will also give an overview of the organisational development during this period.

1.4.2 MSc redesign

The goal of the MSc redesign, which started in 2019, was to address the concerns expressed in two educational reviews and in particular to revise and expand the contents of the existing programmes in line with changes in societal demands. Therefore, the existing AES and CE MSc programmes were transformed into three MSc programmes. The *revised* MSc programmes are Applied Earth Sciences (AES), Civil Engineering (CE) and a *new* MSc programme Environmental Engineering (EnvEng). These three programmes have been taught since of September 2022, together with the existing two cross-Faculty programmes TIL and CME and the AGP cross-university programme.

The connection between education and research has been strengthened by the MSc redesign, as has the connection between the research domains of the seven departments in the Faculty. The MSc programmes are aligned with the major, complex challenges facing our society, such as climate change, the energy transition and the transition to a more circular society, combined with our ongoing focus on important challenges such as resilient infrastructure to ensure protection against natural hazards, reliable transportation networks and understanding the Earth's system and its climate.

The redesign started with the following educational framework: all curricula of the programmes are based on modules, defined as thematically coherent educational entities. Moreover, programmes are comprised of, amongst other elements, the following key ingredients:

- a joint Faculty-wide teaching module on *Modelling, Uncertainty and Data for Engineers* (MUDE) for all three MSc programmes;
- the Programme Core, i.e. an MSc-specific teaching module that every student takes prior to the various tracks within the MSc programme;
- space for a multidisciplinary project, cross-over programme modules and electives.

The programmes emphasise fundamentals and have significant multi-disciplinary elements.

Another important outcome of the MSc redesign was the design of team-based teaching with a mechanism to ensure a structurally balanced teaching workload. This created a better balance in educational load amongst our colleagues, thus mitigating the risk of losing staff through burn-out in systematically overloaded groups.

An interesting side effect of the intensive MSc redesign process was a strong increase in cross-departmental awareness and collaboration in research, especially amongst early-career staff. The Faculty-wide MUDE and cross-over modules and the programme-wide core modules significantly contributed to this.

1.4.3 Relevant developments over the past period

A number of external events and structural developments influenced activities at the Faculty over the review period. The latter includes the increasing importance of the UN Sustainable Development Goals as a leading principle for academic research, the rapid development of artificial intelligence (AI), and geopolitical developments leading to increasing concerns regarding knowledge security. The former includes a significant increase in government spending on higher education and the effects of the Covid epidemic. More specifically, this led to the following developments over the past period:

1. Governmental investment

a. Extra direct funding

Over the past years, the Dutch government has significantly invested in higher education via several large 'Sectorplan' programmes in general universities and universities of technology. Additional funding became available through the so-called 'Van Rijn' and the 'Study Loans Act' programmes, which resulted in the Faculty receiving the following additional funding during the assessment period (Table 1). Subject to various review criteria, all these additional funds are meant to become a permanent component of the Faculty budget. This additional funding has led to an increase of 16 Academic Career Track positions, 40 positions for PhD candidates and positions 17.4 positions for support staff.

Table 1 Additional direct funding to the Faculty during the assessment period (x 1000€).

	2017	2018	2019	2020	2021	2022
Van Rijn	0	0	0	1555	1902	3155
Study Loans Act	900	900	900	900	1500	1800
Sector Plan (T-1/2 and AMW)	0	0	1750	1750	1750	3300

b. Van Rijn – report

At the request of the Ministry of Education, Culture and Science, the Van Rijn committee reviewed the funding of education and concluded that higher education should become less dependent on student growth for funding and that a larger part of the budget should be allocated to science and technology education. TU Delft developed a programme to distribute the funds within the university. The Faculty receives an annual allocation of 3.155m€ (2022) to increase the number of teaching staff and to strengthen educational support. Six of these positions are Academic Career Track Assistant Professors and have a research profile. The Delft Artificial Intelligence (DAI) labs (section 4.3.4) are also funded via this scheme.

c. Student Loans Act

When the Student Loans (Higher Education) Act was introduced and the allowance for students was abolished, it was agreed that the funds released would be invested in education quality. The additional funding has grown to 1.8m€ and is primarily spent on teaching staff in order to make it possible to maintain the quality of our education, especially the intensive, small-scale teaching methods used at TU Delft, even in the face of increasing student numbers. Within this programme, the Faculty hired 7 Academic Career Track Assistant Professors.

d. Sectorplan

In 2019, the Dutch government made funds available annually for strengthening academic research in technical and natural sciences. With these so-called Sectorplans, the Ministry of Education, Culture and Sciences strives to reinforce the foundation of the natural and technical science by attracting new research talent in order to expand research capacity. The Sectorplan also contributes to overarching goals such as more strategic cooperation between universities, increasing diversity and strengthening education, research and valorisation.

The first round of the Sectorplan (Sectorplan T1) focused on technical sciences and had a package related to *Civil Engineering*, with an annual budget of 1.75m€ granted to finance 12 Academic Career Track positions 10 of which for the Civil Engineering departments. Thereafter, the Faculty benefitted from the Earth and Environmental Sciences Sectorplan (Sectorplan AMW, 0.87m€ in 2022 increasing to 2.6m€ in 2023, funding 18 Academic Career Track positions, 7 of which for the Civil Engineering departments, and 4 technicians, 2 of which for the Civil Engineering departments) and from the second round of the Technical Sciences Sectorplan (Sectorplan T2, 0.68m€ in 2022 increasing to 2.4m€ in 2023, funding 9 Academic Career Track positions, of which 8 for the Civil Engineering departments).

2. COVID-19

The worldwide COVID-19 pandemic started in late 2019 and led to a lockdown in the Netherlands beginning on March 11th 2020 and lasting until March 2022. As of March 11th 2020, the default was to work from home, which was strictly applied by TU Delft. Scheduled work at the Faculty was only possible in exceptional cases (experimental work, educational tasks that could not be carried out at home, and in case of mental/physical health) and followed strict rules. In general, offices were closed, experiments were minimised, and education was shifted to online. Research kept pace and, when possible, it was redirected to computer-based work while conferences and meetings also shifted to online. After more than a year since the end of the pandemic, we are proud of what has been achieved despite the difficult situation. As an example, the number of PhD defences did not significantly change, although several experienced a delay of typically three months, demonstrating that we managed to continue our research activities. However, we do feel the impact on our employees and students, which mainly concerns social effects, such as having missed social interaction, not being able to visit family abroad, feelings of loneliness and being cut off from the regular academic environment.

3. Sustainable development goals

In 2015, the United Nations formulated the 2030 Agenda for Sustainable Development: an urgent call for action on the formulated seventeen Sustainable Development Goals (SDGs)[4]. The SDGs have been increasingly integrated within society, governmental policies and funding agencies. The SDGs have been of great value in providing direction to the Faculty in defining its research strategy. The Faculty hosts the TU Delft Global Initiative, whose motto clearly addresses its commitment to the SDGs: ‘Science for the benefit of people. All people. Worldwide.’

[4] https://sdgs.un.org/goals

4. Artificial Intelligence (AI)
The impact of AI, Data and Digitalisation technology can be felt in almost all aspects of science and society. This is further exemplified by the fact that it is prominently present on every agenda, both nationally and internationally. TU Delft recognised this important development, and in order to retain and strengthen its position as a world-renowned university of technology, it started a programme to include state-of-the-art AI, Data and Digitalisation in its core activities of research, education and valorisation. Over the course of 2020-2021, TU Delft established a total of sixteen TU Delft AI labs where experts in AI *foundations* work together with experts in AI *challenges*. Through these Delft AI labs (DAI), expertise and innovation in AI, Data & Digitalisation are used to advance expertise and innovation with AI, Data & Digitalisation, thereby increasing the impact of AI at TU Delft in science, design engineering and society. The Faculty currently participates in four DAI labs: AIDRO (AI for sustainable water management), SLIMMlab (statistical learning for intelligent material modelling), CityAI (where data, AI and behavioural theory come together) and XaiT-lab (eXplainable AI Twins for Resilient Cities). The Faculty also hired three new Academic Career Track Assistant Professors and 10 PhD candidates within this programme.

5. Knowledge security
Knowledge security in research and higher education received increasing attention as of 2020. The rationale was expressed in the Ministry of Education, Culture and Science's letter to Parliament dated 27 November 2020:

'World-class higher education and research are not possible without international collaboration and academic talent from all over the world. Dutch knowledge institutions' leading position and good academic reputation depend on the academic freedom that is guaranteed in the Netherlands, and on their openness to the rest of the world. At the same time, however, we are currently seeing a re-emergence of competition based on power politics between states. When states promote their own interests, this may affect the interests of other states. Acquiring advanced knowledge is a strategic objective for a range of state actors, for economic or military reasons for example. This kind of (advanced) knowledge is also available in the Netherlands. When state actors actively attempt to acquire this knowledge, our interests may be harmed. Though not entirely new, these developments do mean that we must now expeditiously review our existing policy and the way it is implemented.'

TU Delft started a Knowledge Security programme to ensure compliance with national and EU policies. TU Delft guidelines concern increasingly strict rules on the screening of applicants (both staff and students) and the start-up or continuation of cooperative research/educational programmes with specific countries, including China, Iran and Russia. Screening criteria include the exclusion of individuals associated with specific universities or research institutes and the exclusion of emerging key technologies or those with a risk of 'dual use' for military applications. Because the underlying national and EU policies are currently undergoing rapid development, the TU Delft Knowledge Security programme is, necessarily, also in a state of flux which causes uncertainty amongst research and support staff.

1.4.4 Physical safety and IT security
The Faculty highly depends on physical and IT-related assets to do its research. Safeguarding these assets against internal and external hazards has received increasing attention over the past review period. These hazards do not only potentially affect the availability of assets, lead to injury or more, but could also harm public opinion. In 2018 we have started an extensive HSE risk management project to improve our performance through the development of an HSE management system. This was also driven by our role as educators of future engineers, many of whom will be employed in industries with high HSE risks.

With the help of an external consultant, an HSE statement stressing the commitment of the Faculty MT, new policies and renewed procedures were developed which created a foundation for the implementation of an improved safety culture. We employed our own Faculty Safety Officer (FSO) while the arrival of a new HSE advisor also helped to step up our level of activity. More recently, as part of the compulsory Risk Inventory & Evaluation of the Netherlands Labour Authority we assessed our progress and composed a Plan of Action to improve on several points of concern. This process is driven by the Faculty MT in close cooperation with the HR function, our HSE-advisor, FSO and an external HSE consultant.

The focus of our IT security activities is on preventing downtime (e.g. through successful ransomware attack), loss of data (with general data protection regulation-related (privacy) and/or research consequences) or hostile takeover of physical equipment that can be operated remotely. IT security has received rapidly increasing attention at TU Delft level over the past years, which lead, amongst many other activities, to the appointment of Faculty Information Security Coordinators (FISCs), one of which has started work at our Faculty. A large number of procedures has been implemented since, e.g. every device that could be a gateway to our IT-core has been encrypted and can be wiped remotely. However, the specialistic nature of some of our research needs non-standard packages running on devices for which the standard IT security is insufficient. The FISC, who reports to the Faculty MT, therefore supports the Faculty with the inventory of risks, proposing mitigating measures, and analysing incidents.

1.4.5 Organisational structure and culture

A gradual transition in our organisational culture and structure is taking place, and this change is reflected in self-evaluation reports over the years. In earlier versions, the organisational structure and position of Full Professors were dominant in the report. The 2017 self-assessment was the first time we presented the departments on the basis of themes instead of sections (which were represented by Full Professors). This highlighted the shift from a pyramid-shaped organisation towards a new organisational form.

Over the past period, we have experimented with various forms of organisational structures within the departments with the aim of creating more departmental coherence, a less hierarchical structure and room for increased participation of early-career staff, in particular (Academic Career Track) Assistant and Associate Professors. Generally speaking, the role of sections as nearly independent sub-units has been strongly reduced and, as a matter of policy, decisions about finance, strategy and staff (new hires) are taken primarily at department level. Two of the civil engineering departments (Transport & Planning and Engineering Structures) have more actively experimented with a new organisational structure. As a result, we have developed a set of shared starting points and boundary conditions (so-called Departmental Organisational Principles) within which the departments can choose their organisational model. This balances the traditional ‘pyramid’ on one side and a totally flat ‘PI model’ (Principal Investigator) on the other, such that we increase the freedom of individual researchers to excel while maintaining a considerable degree of cooperation and teamwork. Each department will elaborate on their chosen model in their respective chapters.

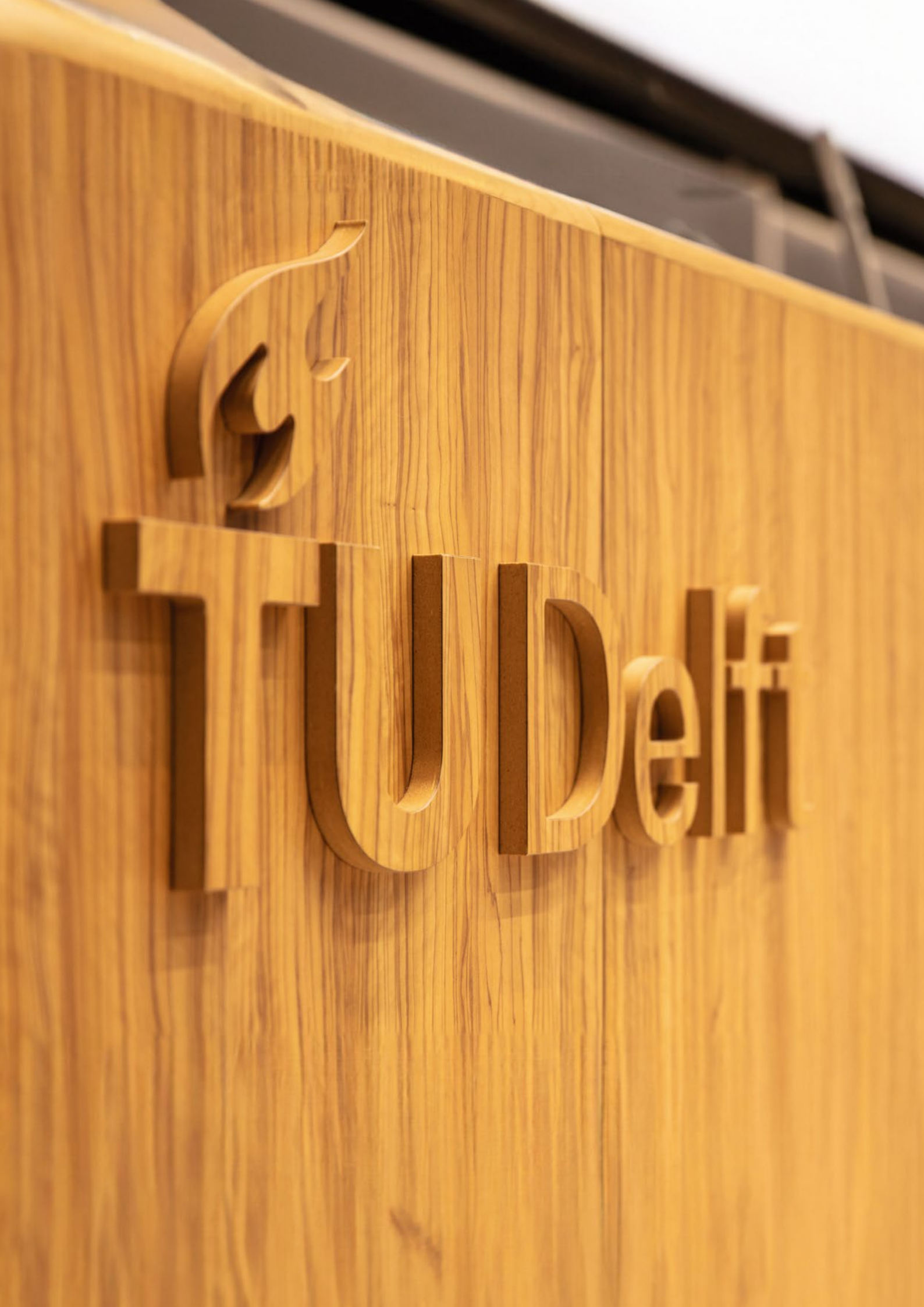
In the process of changing organisational structures, we also saw a more engaged early-career staff taking responsibility and seeking more transparency and recognition. Several initiatives are linked to this transition, such as bestowing the ius promovendi on experienced Associate Professors, the appointment of Associate Professors as section leaders and the conscious decision to invite them to take the lead in the educational revision of our MSc programmes. The initial project team for the MSc revision, which designed the overall structure and main content (tracks and cross-programme modules) mainly consisted of (Academic Career Track) Assistant and Associate Professors. Thanks to their fresh perspective on the current and desired future contents of our educational programme, we have ended up with a significantly renewed and improved curriculum.

In the writing process of the self-evaluation for the midterm of CE 2017-2020, early-career staff were invited to assess our academic culture. Having insight into the employees' perspective, the Faculty MT learned that not all their good intentions were well-received by our employees and that this was sometimes perceived as a lack of transparency. This emphasised the importance of communicating the steps we were taking to support our employees; involvement and communication are as important as new policies. The transition from Tenure Track to Academic Career Track (see chapter 5) is a good example of adapting policies to changing circumstances and demands.

Recruitment and selection of new personnel have also developed; whereas in the past we mostly focused on finding successors for retiring Full Professors to maintain the disciplinary expertise in established fields (usually embedded in sections), we now focus on hiring more early-career (Academic Career Track) staff in fields that are considered to be of strategic future importance (decided at departmental level). Moreover, rather than strictly defining job profiles, we now often aim for excellent candidates using broadly defined profiles. This has proven to be a particularly good practice for attracting female candidates, e.g. through the Delft Technology Fellowship, but has a much broader impact. In the search for excellent staff, we are changing our recruitment and review procedures (Recognition & Rewards programme), possible career paths and our expectations regarding leadership (see chapter 5).

1.5 Strategy for the next six years

The strategy for the Faculty follows the six-year cycle of the university. The current TU Delft Strategic Framework 2018-2024 will be revised in 2024 along with the long-term Faculty plan. The Faculty MT is preparing for a review of the Faculty strategy and its implementation over the past years. The outcome of the various external research and educational assessments over the past period, including the current Civil Engineering research assessment, will be essential input for this review. Another important aspect in the Faculty strategy review process will be TU Delft's 'Campus Rotterdam' plan (formerly known as 'Contours 2030'), which was initiated last year by the TU Delft Executive Board with the aim of significantly increasing student numbers in combination with a potential new campus in Rotterdam. The Board has defined several priority areas for the development of new educational programmes, of which several encompass core activities of our Faculty, in particular *Climate & Energy Systems Engineering, Climate Resilience and Adaptation*, *Cities & Mobility* and *Critical Resources & Recycling*. Grasping these opportunities for expansion while maintaining or increasing our current strength in research and education will be a significant challenge and we welcome the committee's opinion on this aspect.


TUDelft

2. Open Science

2.1 Introduction

The new SEP 2021-2027 introduced Open Science as a specific aspect. Since Open Science was not included as a specific aspect at the start of the evaluation cycle, its starting point for the assessment cycle is the self-evaluation in the midterm of 2017-2020.

Open Science is defined as an inclusive construct that combines various practices, aiming to:
- Make multilingual scientific knowledge openly available, accessible and reusable for everyone;
- Increase scientific collaborations and sharing of information for the benefit of science and society; and
- Open the processes of scientific knowledge creation, evaluation and communication to societal actors beyond the traditional scientific community.

The evaluation of this specific aspect relates to how *'… the unit organises and actually performs its research, how it is composed in terms of leadership and personnel, and how the unit is being run on a daily basis*'.

This chapter is written in close cooperation with the support staff and scientists mentioned in this chapter who implement Open Science as the default at Faculty and University levels.

2.2 Mission and strategic aims of the past six years

In the past six years, the concept of Open Science has grown into a more professional framework at TU Delft. This led to the introduction of the TU Delft Strategic Plan Open Science 2020-2024 in 2019, with its roots firmly embedded in the TU Delft Strategic Framework 2018-2024. With 'openness' being one of TU Delft's major principles, the Strategic Plan defines a clear-cut mission for TU Delft as follows:

TU Delft's mission is to tackle all areas of scholarly engagement where restrictions limit the flow of academic knowledge, by making Open Science the default way of practising research and education.

To this end, the strategic aims are twofold:
1. Adhering as much as possible to FAIR[5] to disseminate the various types of resources for the benefit of the general public as well as TU Delft researchers, lecturers/ professors and students.
2. To create an ecosystem in which scientists can perform and are supported in the practice of Open Science as the default.

TU Delft has developed an Open Science framework (Figure 8) that interconnects Open Education, Access, Publishing, FAIR Data, and Software with cross-cutting themes. The cross-cutting themes connect support processes from Human Resources (Recognition & Rewards), Legal Services (Fruitful Collaboration with Third Parties), IT and the Library (Skills for Open Science) to the practice of Open Science.

[5] FAIR stands for Findable, Accessible, Interoperable and Reusable.

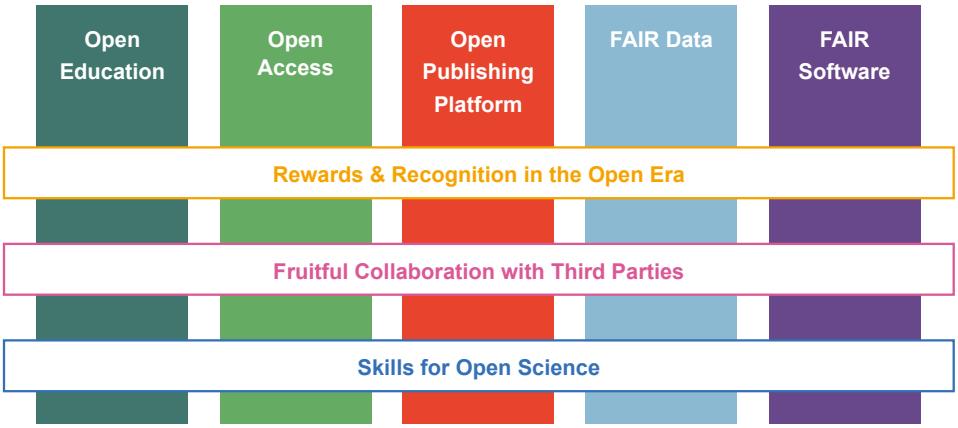


Figure 8 TU Delft Open Science framework.

Moreover, TU Delft has embedded its Strategic Plan in its organisation by working with a yearly Open Science plan and evaluation cycle to further develop Open Science practices at TU Delft. This was a natural improvement upon initiatives that were already in place and supported at the Faculty and TU Delft levels, on elements such as Open Access publishing and Data Management. 'Open Science is the default' has been the policy for this Faculty's research for the past six years (and beyond).

2.3 Follow up from previous assessments

Embedding Open Science in the yearly R&D cycle and assessment procedure of the CEG Career Development Committee
At the national and TU levels, the Recognition & Rewards programme integrates Open Science within HR policy and processes. Besides its incorporation in R&D talks, HR's role with respect to Open Science also involves (i) integration of Open Science principles in the Academic Career Council, (ii) implementing "Taverne" (see section 2.5) in the labour agreement, (iii) focusing on Open Science aspects within recruitment and (iv) a broader vision on training and career paths for scientists and support staff. This has just partly been realised. The development of most aspects is now part of the Recognition & Rewards crosscutting theme.

Make the role of the data steward clearer and ensure the visibility of the data steward
After the midterm, more training for PhD candidates and support relating to data management plans was given. This increased the visibility of the data steward and increased requests for support. Adding to a higher visibility, the Faculty started recruiting a 2nd data steward (started in March 2023). The need for additional capacity was motivated by more attention among MSc students for data management and the complexity of data management with respect to human research and ethics.

Formulate a policy on how Open Science can lead to further development and valorisation of the research carried out.
This recommendation is now embedded as one of the three Open Science goals, namely: '*… and to open the processes of scientific knowledge creation, evaluation, and communication to societal actors beyond the traditional scientific community*.' The goal is to reach people beyond academia, such as practitioners, policymakers and non-field experts by using other channels of communication (see the use of PlumX metrics in Figure 11 and Table 5). This has led to multiple good practices.

2.4 Strategic process of the past six years

2.4.1 Review process from 2017-2020

At the beginning of the research assessment period, reporting on the percentage of Open Access publications per unit was already in place. At that time, the Library had limited funds to pay for fees in order to publish Open Access.

In 2018, the TU Delft Research Data Framework Policy was published marking the start of data management. CEG was one of three Faculties that started with a pilot to employ a data steward for proactive data management. In the workflow, a supportive role was developed for the data steward to guide the process of data management planning, storage and archiving. The main goals of the pilot were the design of these data management processes and raising awareness within the Faculty. The pilot was successfully concluded in 2020 with the incorporation of data stewards at all Faculties.

2.4.2 Strategic process from 2020 onwards

In preparation for the midterm assessment of 2017-2020, an analysis was made on the extent of Open Science within the Faculty (see chapter 2 Open Science, self-assessment midterm CE 2017-2020). This analysis focused on the availability of a TU Delft and, if needed, a Faculty policy on the integration of Open Science within the research cycle[6], on the available support at Faculty and/or university level and availability of the management information. We assess the strategic state of Open Science, i.e. Open Access, FAIR Data and FAIR Software, as well as available support and management information in the following paragraphs.

Open Access is assessed as developed. TU Delft has a university-wide Open Access policy in place, full integration within the research cycle is reached and management is periodically informed on Open Access. In the early stages of the application process for a research project, contract managers discuss the necessary budget for publishing fees and archiving costs of data. Once peer-reviewed articles are published, the Library automatically retrieves them from the internet, verifies their Open Access status and archives them within the TU Delft Research Repository and Current Research Information System (Pure). Pure periodically delivers management reports on the Open Access percentage of the Faculty and each unit. This initiates the conversation with researchers regarding their choice for Open Access or for a motivated opt-out.

FAIR Data is developing towards compliance. A TU Delft policy is in place (TU Delft Research Data Framework Policy)[7] and further integration in the research cycle is in progress. Data stewards are engaged in the research process, and contract managers discuss budget needs for data management in the application process for research projects. Moreover, the four Technical Universities have established a sealed data repository (4TU Research Data Centre), which can archive datasets of scientists.

FAIR Software is in an earlier stage of development. During the midterm review, TU Delft published its Research Software Policy. This document gives a preliminary workflow to determine the possibility of Open Software publishing or, instead, how to claim IP. Management information is necessary to provide feedback to researchers and management regarding policy decisions and changes. The option to create Faculty-level reports on Open Data and Software, however, is limited due to the lack of international databases available for Open Access reports. The only source available for reporting is the Current Research Information System of TU Delft, which only offers local (i.e. TU Delft-related) data regarding datasets and software.

[6] The research cycle is considered to consist of the following steps: idea – getting funding – doing research – output.

[7] https://zenodo.org/record/4088123/files/TU%20Delft%20Research%20Data%20Framework%20Policy_June%202020.pdf?download=1

Raising awareness within the Faculty and involving support services are crucial for the integration of Open Science. Support services are very important for creating TU-wide policies and work processes on the identified dependencies on IT, Library, Legal Services and HR aspects. Their involvement is, more concretely, embedded in the cross-cutting themes of the Open Science – Framework (see Figure 8, 2. Mission and Strategic TU Delft Open Science framework).

2.5 Evidence

2.5.1 Open Access

In the future strategy of the Midterm Research Assessment, we focused on (i) raising the percentage of Open Access publication, (ii) lowering the total costs for subscriptions with publishers and (iii) following up on developments such as publisher deals, Taverne[8] and Plan S[9]. The Taverne amendment offers authors the possibility to claim short research publications, funded by the Dutch government, to be freely accessible six months after publication. At the EU level, Plan S embodies similar efforts by the European Union to make publications, paid by the EU, directly Open Access.

2.5.2 FAIR Data

In the future strategy of the Midterm Research Assessment, the focus was on embedding the data stewards within Faculties, developing workflows, supporting data managers at TU Delft level and on further developing the data reporting options.

2.5.3 FAIR Software

The future strategy of the Midterm Research Assessment focused on the integration of FAIR Software in the process, support at TU Delft level and the availability of management information.

2.5.4 Management information

The future strategy of the Midterm Research Assessment focused on developing management information related to FAIR Data and FAIR Software, oriented to process indicators, such as the number of trainings provided, number of Data management plans, registered datasets or software in the 4TU Research Data Centre.

2.6 Accomplishments during the past six years – research quality and societal relevance

Open Access

One of the Faculty's major developments pertains to the Open Access status of its research. Table 2 shows that it has surpassed its goal of 85% by 12%-points, reaching an average Open Access rate of 97% in 2022.

The substantial increase in Open Access publications can be attributed to CEG's incorporation of Taverne and Plan S. In 2019, CEG started a pilot to facilitate its researchers to claim this right, and by 2023 this had been embedded on a university-wide level in our appointment policy, including an option to opt-out. Moreover, the Faculty is making additional efforts to inform research staff, postdocs and PhD candidates about Plan S by creating a webpage dedicated to more in-depth information on the plan.

[8] https://www.openaccess.nl/en/in-the-netherlands/you-share-we-take-care
[9] https://www.coalition-s.org/why-plan-s/

Table 2 Development of Open Access status of publications across the departments over the period 2017-2022. The bottom right block contains the total.

		Total						ES					
		2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022
YES	#	296	484	554	709	749	922	44	70	92	100	128	183
	%	51%	60%	63%	77%	82%	97%	47%	45%	55%	66%	73%	94%
NO	#	285	317	320	210	169	30	50	87	74	51	48	12
	%	49%	40%	37%	23%	18%	3%	53%	55%	45%	34%	27%	6%

		HE						TP					
		2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022
YES	#	65	98	146	166	158	217	55	124	99	147	135	134
	%	53%	59%	66%	76%	82%	98%	53%	78%	69%	77%	89%	98%
NO	#	58	68	74	51	34	4	49	35	45	44	17	3
	%	47%	41%	34%	24%	18%	2%	47%	22%	31%	23%	11%	2%

		WM						3MD					
		2017	2018	2019	2020	2021	2022	2017	2018	2019	2020	2021	2022
YES	#	90	125	146	220	169	221	61	88	101	110	159	167
	%	59%	69%	64%	81%	80%	99%	44%	49%	62%	81%	85%	95%
NO	#	62	57	83	50	42	3	79	91	63	25	28	8
	%	41%	31%	36%	19%	20%	1%	56%	51%	38%	19%	15%	5%

On national and TU Delft level Open Access deals have been made regarding Open Access publishing at no cost or at a discount.[10] The increased attention and effort towards Open Access publishing has not, however, led to a decrease in subscription fees at TU Delft (Figure 9). Therefore, the Library has commissioned a report to provide a new vision on how to manage access to publications in scholarly journals (TU Delft: A vision for 21st century scholarly collections).[11]

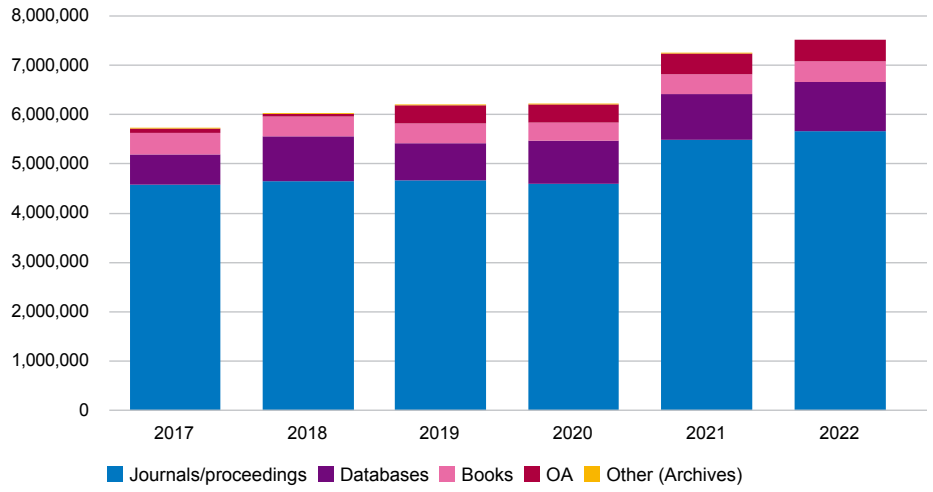


Figure 9 Collection costs TU Delft (in €).

[10] TU Delft open access deals with publishers (https://www.tudelft.nl/en/library/library-for-researchers/library-for-researchers/publishing-outreach/tu-delft-open-access-deals-with-publishers).
[11] A Vision for 21st-Century Scholarly Collections: a report for the Delft University of Technology Library | Zenodo

To monitor the Open Access status of their research, monthly Open Access reports are available for the departments via MiFocus, the management information system of TU Delft. The official yearly progress of Open Access publications is reported by the TU Delft Library each April, pertaining to the previous year. During the compilation of the data in this report, an additional effort is made to make more publications publicly available.

FAIR Data

The state of FAIR Data within the Faculty has improved significantly through further integration in the research cycle. At TU Delft level, policies on data management and the vision for Research Data Management Skills have been published. In 2020, the Faculty issued the CEG Research Data Management Policy, which provides the baseline for responsibilities and workflow. PhD candidates follow a mandatory data management course before the Go/No-Go meeting.

Moreover, a lively community of data stewards has been established at a university-wide level, which is coordinated by the Library with at least one data steward per Faculty. The rise in demand for support (see Table 3) has led CEG to hire a second data steward. Increased demand for support is related to two factors. On one hand, we have complex requirements for Data Management Plans (DMPs) with respect to research and ethics. On the other hand, the number of MSc students applying for support on DMPs during their MSc thesis has increased significantly.

Table 3 Increase in number of DMPs of research staff, postdocs and PhD candidates only. It is not yet possible to display the (growth in) number of DMPs of MSc students.

	Year					
Department	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
ES			1	15	12	13
HE	1	1	3	25	15	25
TP			3	17	23	25
WM	1		3	34	37	22
3MD				15	24	18

The Library and the data stewards provide information and awareness sessions for PhD candidates, postdocs and research staff. To this end, DMP online[12] - a software tool to support data management planning - has been implemented and is actively being used. Besides the contribution of data stewards to Open Data, close cooperation now exists between contract managers and IT on data storage and archiving costs.

Linking datasets in publications to the article itself helps to increase the data's visibility (see promotional flyer in Figure 10). The data is found and accessed more easily. To help researchers make their data more FAIR, the Library (in close cooperation with IT) has established the Digital Competence Centre[13]. Besides helping researchers make research data more FAIR, the centre also aids researchers in improving research software and applying best 'computing' practices to increase the efficiency of the research process. In 2021/2022, 11 projects were executed for CEG and three are still running.

[12] https://dmponline.tudelft.nl
[13] https://www.tudelft.nl/en/library/library-for-researchers/library-for-researchers/setting-up-research/dcc

Figure 10 Promotional flyer Open and FAIR Data.

Reporting on the output of FAIR Data (Table 3) is still a challenge. It is limited to the output that is stored in the 4TU Research Data Centre, which partially comprises the research done at TU Delft. This will remain a limitation until a worldwide registration of output, similar to WoS/SCOPUS for articles, is available for datasets.

Open software

The progress on FAIR Software has been more modest. In 2021, TU Delft published its Research Software Policy[14] and Guidelines on Research Software: Licensing, Registration and Commercialisation. As a result, researchers are given training in Software Carpentry and Code Refinery, and software engineers at the TU Delft Digital Competence Centre (DCC) are available for support in research projects. Moreover, GitHub (a code management system) is connected to Pure, providing basic functionalities to report on software.

[14] https://zenodo.org/record/4088123/files/TU%20Delft%20Research%20Data%20Framework%20Policy_June%202020.pdf

Integrating FAIR Software into operational processes is challenging. On one hand, choices on software are made during the proposal phase of the research cycle, similar to Open Access and FAIR Data. On the other hand, software is also often the outcome of a 'free' creative process. Therefore, the question arises of how support staff can be involved in the choice of open or commercialised software.

If we analyse the datasets and software that are available in Pure, we do see the results of our increased effort to make data and software more open. Table 4 shows that the default for publishing datasets and software has shifted from closed to open in the past six years.

Table 4 Open Access status of datasets and software across all departments at CEG per publication year over the period 2017-2022.

	Year					
Open access status	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Open	1	4	8	36	57	82
Embargoed					1	
Unknown	30	31	49	40	7	8

Management information
The evidence on management information has been integrated into the first three paragraphs of this chapter.

Onboarding
Despite the significant rise in Open Science output, awareness of its importance has not seen an equivalent increase, making it difficult to have Open Science as the default for our research. We experience challenges in informing our scientists on the do's and don'ts of Open Science. The diverse community of employees not only brings diverse backgrounds but also different starting points for Open Science. Therefore, there is a strong feeling that training at an individual level is needed to align the different backgrounds and improve Open Science practices at the Faculty. The added value of general workshops on Open Access was limited after the integration of Open Access in the research cycle, which is why they were stopped. On Open Data, we have a workshop given by the data steward. A possible alternative is the MOOC Open Science[15] of the Library or The Informed Researcher workshop.

We are aware that making Open Science the default is not only limited to scientists and needs the strong involvement of support staff. We need this broader community to embed and advocate Open Science as the default; that is the default within the research cycle and the default within work processes of the support services such as HR, Legal and Procurement. Although this will take time and effort, it will be essential for the success of Open Science at TU Delft.

Effect of Open Science
The aim of Open Science is to (re-)use scientific output. It is difficult to estimate whether the use of our research by others than our peers has increased or not. We mainly report on whether our work is openly accessible. The use of research, however, is not the same. Citations are used within the scientific community to measure the use of research. This does not reflect the use by others.

[15] https://www.edx.org/learn/science/delft-university-of-technology-open-science-sharing-your-research-with-the-world

Therefore, we follow the development of PlumX metrics to assess whether our work also has an outreach towards others than our peers. PlumX divides this outreach into Usage, Captures, Citations, Mentions and Social Media. See Figure 11 for a more detailed explanation of these categories.

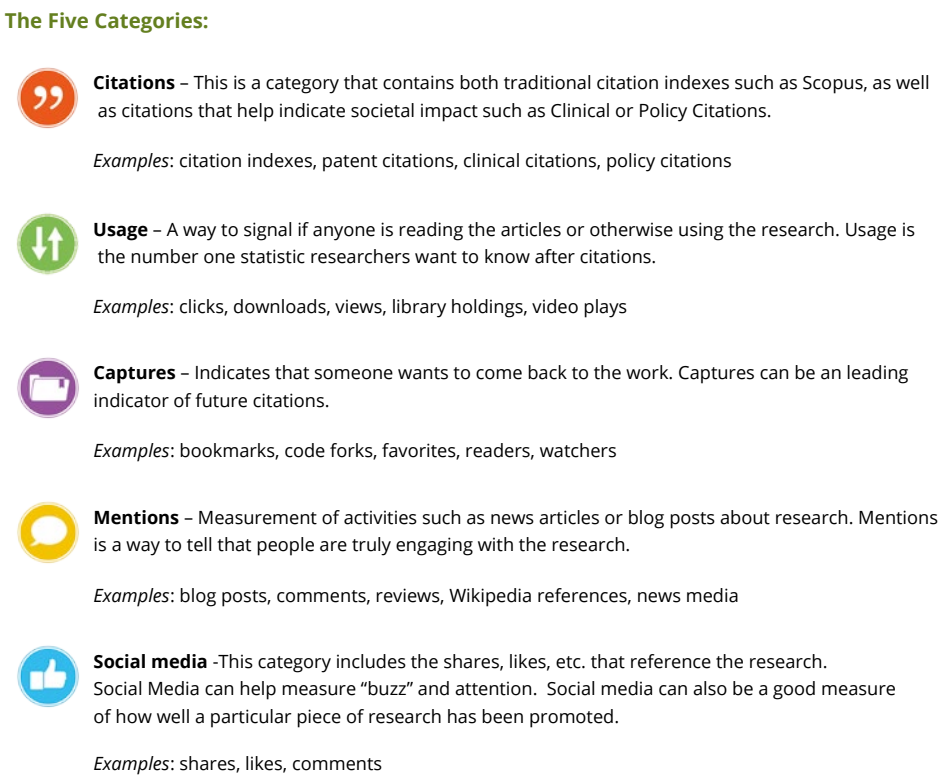


Figure 11 A detailed explanation of PlumX metrics.[16]

Table 5 displays the PlumX metrics per publication year for the research across all departments. The most interesting development with respect to societal impact is the growth in captures and social media presence since 2017. Captures show that people keep returning to our research, while increased attention on social media indicates that the promotion of our Open Access research has improved as well. Although there is a decrease in usage and citations in the last two years, this is most likely related to the fact that the research has only been available for one or two years.

Table 5 PlumX metrics for research across all departments per publication year over the period 2017-2022.

	Publication year					
PlumX-metric per year	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Captures	939	1.258	1.602	2.178	1.715	1.860
Citations	420	561	648	756	496	166
Mentions	4	2	4	17	19	9
Social media	46	304	244	381	613	589
Usage	2.736	1.087	855	508	32	103

[16] https://plumanalytics.com/learn/about-metrics/

Cross-cutting themes
The cross-cutting themes were not used as a category in the midterm review, although references were made to elements of these themes. No direct outlook was mentioned in the midterm either, although programme-level improvements are defined in the Open Science workplans, i.e. the yearly plan and evaluation cycle.

Rewards and recognition in the Open Era
In 2021, TU Delft published the TU Delft Recognition & Rewards Perspective[17], which focuses on five levels of recognition and rewards: to perceive behaviour and contribution, to acknowledge products, to value the use of products, to appreciate academics and to reward academics. This perspective is embedded in the Academic Career Track policy and is also a strong stimulus for Open Science as default. In the Open Science Programme 2022 workplan, focus was on defining criteria for valorisation, updating academic criteria, and metrics.

The recognition and rewards perspective are not well known among research staff and, therefore, the full potential of the stimulus has not been reached. Within the Faculty, additional effort will have to go towards informing new and existing staff on this perspective during onboarding, the R&D cycle and the review in the Academic Career Council. This will further motivate research staff to switch completely to Open Science as default.

Fruitful collaborations
The Faculty experiences (new) challenges on aspects of human research/ethics, ownership, collaboration with third parties and the goals of Open Science and GDPR. This is partly related to more social awareness in recent years but also pertains to the complexity of the matter. Supporting scientists on questions related to the possibilities and impossibilities regarding these challenges emphasises the need for expertise on this matter within the Research cycle. A clear policy and workflows are needed to instruct, support and easily connect second-line experts to the individual researchers.

Skills for Open Science
The Skills cross-cutting team developed an overview of skills needed to apply Open Science principles in daily research practices. While getting a better understanding of the skills needed, courses and trainings were developed and held to support researchers. For Research Data and Research Software management, courses are embedded in the Doctoral Education Programme of the Graduate School. PhD candidates can earn credits for completing the courses. The TU Delft Digital Competence Centre (DCC) and the Library are working on developing a vision for FAIR Software training as well.

The following trainings are available for researchers:
- Research Data Management 101, a popular course with PhD candidates, which has led to more complete and well-thought-out DMPs;
- Self-paced online course on ‘Personal Data and Human Subjects in Research’ to complement the RDM 101 course for those working with this category of research data;
- Software Carpentry and Code Refinery;
- The informed researcher course, part of the doctoral education programme, covers open publishing, amongst other topics, and researchers are further supported in open publishing and open access publishing by several Library Services;
- The MOOC: Open Science: Sharing your research with the world[18] is an introductory course about the understanding and application of Open Science principles in daily practice, including an introduction to citizen science. It is part of the doctoral education programme and is held once a year.

[17] https://d2k0ddhflgrk1i.cloudfront.net/TUDelft/Over_TU_Delft/Strategie/Erkennen%20en%20Waarderen%20-%20recognition%20and%20reward/TU%20Delft%20Recognition%20and%20Rewards%20perspective%20def.pdf
[18] https://www.tudelft.nl/en/library/mooc-open-science-sharing-your-research-with-the-world

Relation towards assessment criteria

Open Science has a clear role in research quality and societal relevance by involving and providing research output to a broader audience and making the research reproducible. The choice for Open Science as default is the only choice to stay connected.

2.7 Strategy for the next six years

At the Faculty level, we follow the developments of TU Delft's Open Science Programme. The outcomes of different projects under the Open Science Programme are fit for our purpose and offer sufficient options for improving practices. CEG has been a frontrunner within TU Delft on (implementation of) Open Science projects (e.g. Datasteward, Taverne) and will continue to fulfil this role. This self-assessment, however, has shown us that not all benefits of the Open Science Programme have been collected yet. With this self-assessment and the SWOT (see Table 6) in mind, we define the following focal points for further improvement:

1. Onboarding (new) research staff on Open Science, creating unity in vision and knowledge of the existing ecosystem;
2. In close cooperation with Library and IT, integrate FAIR Software further within the operational process and also with FAIR reporting on process and outcome;
3. Further develop cooperation and implement policies and workflows with the support services on the cross-cutting themes of Recognition & Rewards and Fruitful Collaboration with Third Parties.

Table 6 SWOT analysis Open Science.

	Strengths	Weaknesses
Internal view	• Policy at TU and CEG level in place on Open Science • Workflow Open Access fully automated and management information available • Workflow FAIR Data integrated with Contract Management, Human Research Ethics Committee, IT and Library Services • Own trusted repository: 4TU Research Data Centre • Availability of (also non-Open Access) publications through TU Delft Library	• Integration in operational process and support for FAIR Software not optimal yet • No guidance exists on possible choices to be made on legal aspects such as GDPR, IP rights and the rights/obligations of non-employees • Accurate management information is not available for FAIR Data and Software • Measurement of the effect of Open Science (reuse, outreach to new groups) is limited • A firm embedding of Open Science within the HR, Legal and Procurement policies is lacking
	Opportunities	**Threats**
External view	• Funders and governments support and demand Open Science as the default • The potential outreach of scientific knowledge is growing due to the free access to this knowledge. • The worldwide registration of datasets/ software and citations of this output is developing and can become the foundation for management information on FAIR Data and Software • The focus towards Recognition and Rewards supports the concept of Open Science as the default	• Knowledge security will influence the development of Open Science (Chapter 1) • The revenue model of publishers is still a major influence: whether it is a paywall or OA fees, it hinders the free flow of knowledge • Misuse, misrepresentation and/or misinterpretation of scientific output by non-field experts for a completely different purpose (climate, COVID, etc.) than its actual intention.

3. PhD Policy and Training

3.1 Introduction

In this chapter we present past and ongoing activities in the domain of PhD policy and training and present the strategy and goals of the Faculty for the next years. Acknowledging the importance of PhD candidates, the University Graduate School (UGS) (together with its Faculty component, the Faculty Graduate School – FGS) was founded in 2012 with the main goals of:

1. introducing a digital platform to monitor progress of PhD candidates;
2. broadening the education of PhD candidates, offering courses and activities in the framework of a Doctoral Education program;
3. working on the reduction of the excessively long duration of PhD projects.

This chapter was written by the director of the Faculty Graduate School in close cooperation with Faculty and University Graduate School support staff.

3.2 Mission aim and strategic aims of the past six years

In 2017, the monitoring system (Doctoral Monitoring Application, DMA) and the Graduate Education program were supporting the PhD process adequately. The DMA allowed us to gather and access a large amount of data, which play a key role in our policies. In the period of assessment, the university, the Faculty, and the Faculty Graduate School worked to improve the overall quality of the PhD path and, more specifically, to reduce the duration of PhD projects (henceforth PhD duration) and to strengthen the support offered to PhD candidates (including minimizing/reporting cases of undesirable behaviour). In the vision of the Faculty, PhD duration and welfare are interconnected, as delays are often related to insufficient or inadequate supervision and/or poor wellbeing of PhD candidates. Consequently, this chapter is closely related to the chapter 4 on Academic Culture.

The strategy that was developed aimed at improving PhD success and welfare, adopting a range of soft measures organised along three main axes of action:

1. Monitoring and Improving PhD Selection and Progress: improving the quality of PhD selection interviews and of management of the different milestones of the PhD path (see Table 8), namely GO/NoGO meetings[19] and Yearly Progress Meetings (YPM)[20].
2. PhD Welfare: improving the system offered by the Faculty/university to *support* the welfare of PhD candidates and to *report* undesirable behaviour. As there are overlaps and interfaces between the two, we will refer to both combined as the support & report system.
3. PhD Empowerment: stimulating PhD candidates to take full ownership of their projects and encouraging their participation in activities within departments and the Faculty.

[19] The GO/NoGO meeting is held approximately 12 months after the beginning of the PhD and has the goal of assessing the quality of the project, the supervising team and of the PhD candidate, and to search for ways to improve all three.

[20] YPMs are yearly meetings held to provide a formal assessment of the progress of the PhD project.

3.3 Follow up from previous assessment

Previous assessments (before 2017 and the mid-term evaluation) highlighted several issues, namely:

1. The long PhD duration and its potential causes, i.e. insufficient or inadequate supervision and insufficient attention to welfare of PhD candidates.
2. Lack of transparency in the hiring of PhD candidates and the management of the PhD process (see also chapter 4).
3. High proportion of PhD candidates with prior education from TU Delft.
4. Large proportion of PhD candidates dropping out.

We will address issues 1 and 2 in sections 4 and 5. With respect to issue 3 however, we (in conversation with relevant stakeholders) have decided that this concern is not supported by the data. Although the percentage of PhD candidates with a previous degree from TU Delft varies from one department to the other, in the last couple of years it has consistently been around 30%. Moreover, our PhD population is quite international, and this is something we cherish.

Table 7 Drop-out rate of full-time PhD candidates in the Faculty starting from cohort 2012.

						Discontinued within year:												
Cohort	Started	active	finished	Dropped out	Dropout% until now	1	2	3	4	Dropout within 4 years	5	6	7	8	9	10	11	Dropout after 4 years
2012	49	2	37	10	20%	1	3	2	1	14%	1	2	0	0	0	0	0	6%
2013	50	7	31	12	24%	1	4	2	1	16%	1	1	1	0	0	1	0	8%
2014	58	6	41	11	19%	1	3	2	1	12%	2	2	0	0	0	0	0	7%
2015	54	9	39	6	11%	1	1	0	0	4%	1	0	2	1	0	0	0	7%
2016	91	13	59	19	21%	4	11	0	1	18%	2	1	0	0	0	0	0	3%
2017	97	52	37	8	8%	1	3	1	1	6%	1	1	0	0	0	0	0	2%
2018	88	67	13	8	9%	6	1	1	0	9%	0	0	0	0	0	0	0	0%
2019	67	59	2	6	9%	1	2	3	0	9%	0	0	0	0	0	0	0	0%
2020	78	71	2	5	6%	0	5	0	0	6%	0	0	0	0	0	0	0	0%
2021	93	93		0	0%	0	0	0		0%	0	0	0	0	0	0	0	0%
2022	81	78		3	4%	2	1			4%	0	0	0	0	0	0	0	0%
Totaal	**806**	**457**	**261**	**88**														

No longer subject to change Can still change

Concerning issues 4, we have analysed available data regarding drop-out rates. For the cohorts before 2019 (which have completed their fourth year), drop-out rates range from 4% to 18% during the first four years (see Table 7); cohorts 2012-14, for which sufficient records are available, show a drop-out rate of 6-8%. Note that drop-out rates for cohorts before 2019 (coloured green) are not comparable to rates since 2019 (coloured yellow) because (i) the latter groups have not yet finished four years and (ii) due to the impact of COVID. However, our analysis shows a higher drop-out rate than expected, which will require further analysis.

3.4 Strategic process of the past six years

Building on the recommendations provided in previous evaluations, and on several Faculty and university surveys, we have developed a number of actions during the present evaluation period (in some cases in collaboration with the University Graduate School). These are presented below using the three aforementioned axes (section 2).

3.4.1 Monitoring and Improving PhD Selection and Progress: from single ownership to shared responsibility

The following actions were taken to improve the quality of the selection and progress meetings and the transparency of that process.

Implementing TU Delft guidelines in the Faculty

a) The Faculty and FGS engaged strongly to ensure that university-wide guidelines are implemented. This refers to the 4-eye principle applied to selection meetings, having GO/NoGO meetings and YPMs performed by a committee rather than only by the promotor[21].
b) Implementing new YPM forms (see Table 8), which highlight the importance of finishing the PhD in four years.
c) Supporting the use of the guidelines issued by the University Graduate School to align expectations of PhD candidates and the supervising team during various steps of the project.

Table 8 Timeline of the PhD path.

What	When	Goal
PhD agreement	after 3 months	Define project, supervising team, first activities.
GONOGO	After 9-12 months	Together with the candidate, the supervising team (without promotor) with an external member assess project, supervision and candidate and define ways to strengthen these.
YPM24	After 2 years	Defines the progress of the thesis and the research steps in the 3rd year.
YPM36	After 3 years	Assess the progress of the thesis aiming at draft submission during the following (4th) year.
YPM48	After 4 years	Thesis is not proceeding to schedule, and action needs to be taken.

At Faculty level:

a) The Faculty has put in place a system of Half-Yearly PhD Process Review (HYPPR) meetings. In these meetings, the FGS director, with the support office, meets twice a year with each Department Head and the Department Executive Secretary as well as the HR advisor to discuss the progress of PhD candidates and identify criticalities in their supervision. HYPPR meetings started in 2018 and are considered by all participants to be effective tools to monitor PhD progress. Once a year, the FGS director reports the main findings of the HYPPR cycle to the Dean.
b) New GO/NoGO instructions are given to highlight the goals of the meeting. More concretely, the GO/NoGO meeting has become the moment to assess the quality of the PhD candidate, of the project and of the supervising team, and to find ways to improve these.

[21] In the Dutch system, the ius promovendi, i.e. the right to be official promotor, is assigned to all Full Professors and to Associate Professors who fulfil specific conditions. The promotor is supported by 1-2 other academic staff members, who together form the supervising team.

3.4.2 PhD Welfare (support & report)

TU Delft offers a wide range of services to support the welfare of PhD candidates and to report cases of conflict with the supervising team and of undesirable behaviour (the support & report system). University services are, for instance, the confidential advisors, the psychologists, and the Ombuds Officer. At the Faculty level, mentors assigned to small groups of PhD candidates, the FGS and HR make up the support & report system. To embed this strategy even further, two process have been implemented:

a) At Faculty level, the director of the FGS has frequent contact with the mentors and is regularly contacted by PhD candidates searching for advice or support.
b) At University level, the UGS Board has started a large initiative to make an inventory of existing support & report services and define ways to improve the system.

3.4.3 PhD Empowerment

Empowering PhD candidates, i.e. encouraging PhD candidates to claim co-ownership of their PhD projects, has been a priority of the FGS in the period under evaluation. Numerous initiatives have been developed to support this:

a) Regular introductory meetings with all new PhD candidates.
b) Presentations held for the PhD candidates of all departments to emphasise co-ownership of the PhD process, path, and experience.
c) Instalment of a PhD Council, composed of representatives of PhD candidates of all departments. The director of the FGS meets the council once a month.

3.5 Evidence

The evidence for the three axes is:

1. Monitoring and Improving PhD Selection and Progress
   - Monitoring report on GO/NoGO and YPM.
   - Development of the HYPPR-process.
   - Yearly reports to the Faculty MT on findings of the HYPPR-cycle.
2. PhD Welfare
   - Developing and providing clear information on the services available for support & report to PhD candidates.
   - Collecting quantitative and qualitative data on PhD welfare.
3. PhD Empowerment
   - Support offered in the development of self-reliant behaviour.

3.6 Accomplishments during the past six years – research quality and societal relevance

3.6.1 Monitoring and improving PhD selection and progress

While it is not the task of the FGS (nor the Faculty) to judge the decisions taken during the selection, the GO/NoGO and YPM meetings, the FGS does monitor if and how these events are held. In our experience, there is a correlation between the presence and quality of these meetings and that of the supervision.

Monitoring report on GO/NoGO and Yearly Progress Meetings

During the evaluation period we have seen an improvement of the supervisors' discipline in the following areas:

a) A significant majority of selection meetings are performed with two or more committee members.
b) All PhD candidates have supervising teams composed of more than one person.

c) Submissions of reports on GO/NoGO meetings within six months from the scheduled date have increased to 93% in 2022 (Figure 12a, blue and purple bars). For YPM24 (end of the 2nd year) the percentage has risen to 86% (Figure 12b). For YPM36 (Figure 12c) and YPM48 (Figure 12d) meetings have also climbed to, respectively, 74% and 60%. Until a few years ago, these meetings were not held.

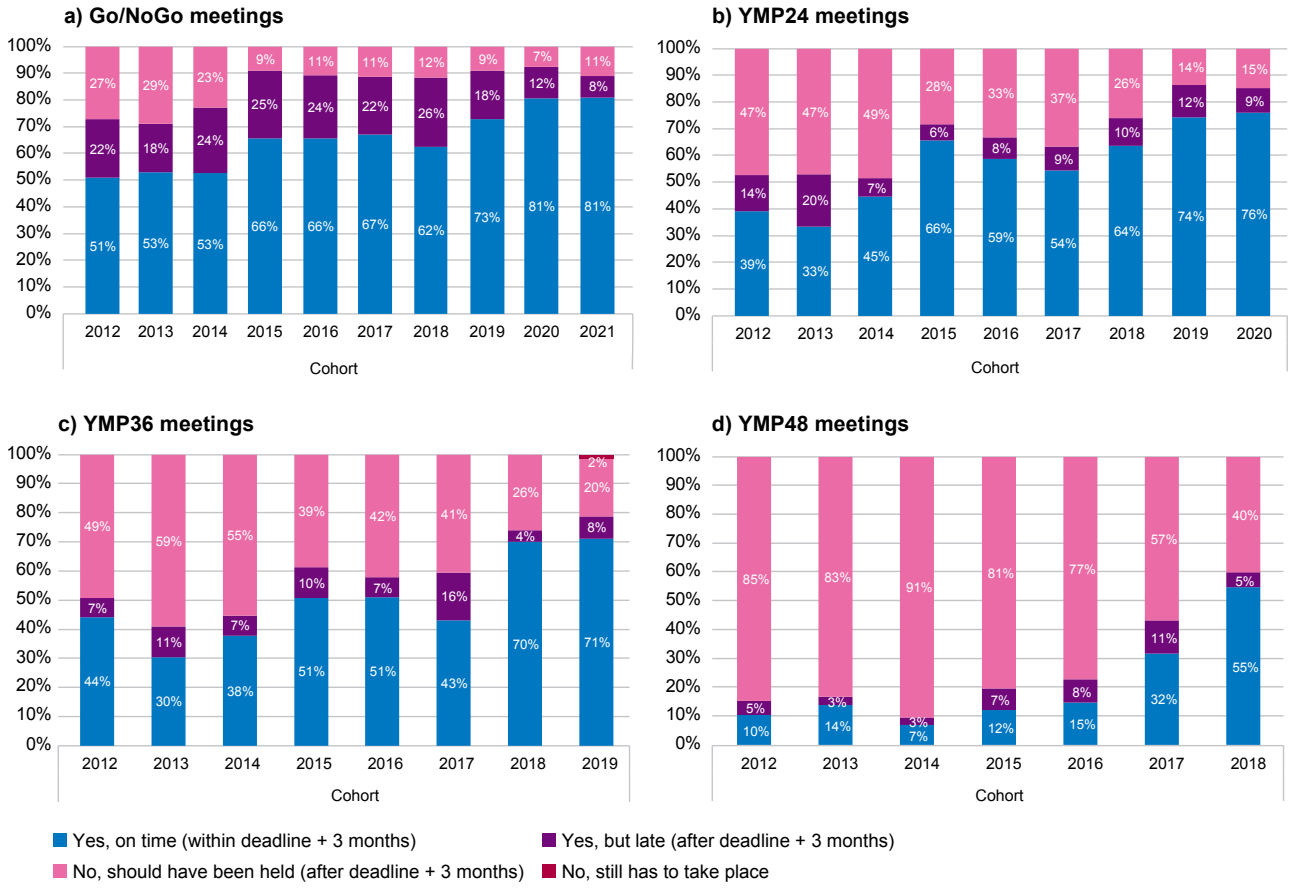


Figure 12 Share of (timely) completion of progress meetings during the PhD path: a) GO/NoGO, b) YPM24, c) YPM36, d) YPM48.

Yearly report to the Faculty MT on findings of the HYPPR-cycle

The necessity to reduce the current PhD duration is now shared within the entire Faculty. There has been a substantial improvement in the quality of the selection of candidates and progress meetings, and most of these now take place according to the guidelines. The HYPPR meetings have proven to be of great importance in monitoring supervision and stimulating departments to carefully look at the progress of their PhD candidates. The improvements achieved in PhD duration are, however, substantially below the ambitions of the university and Faculty of having 70% of PhD candidates finishing their thesis within five years. Therefore, the FGS has started a discussion with the Faculty MT to identify new measures to generate the required change of pace.

3.6.2 PhD Welfare

Developing and providing clear information on the services available for support & report to the PhD candidates

In general, the accessibility, efficiency and accountability of support & report services can be improved significantly. The results of surveys show, for instance, that ca. 35% of

TU Delft PhD candidates describe their welfare as fair to very poor[22]. This emphasises the mismatch between the needs on the one hand and what is offered on the other hand. To begin to address this, a first map providing information on the support & report services is currently being finalised, including information on how they can be accessed. Follow-up on this is needed to bridge the gap between demand and supply of support & report services.

Collecting quantitative and qualitative data on PhD welfare
The director of the Faculty Graduate School has had conversations with a substantial number of PhD candidates (>20) and supervising teams (>10) requiring support. These conversations have generally led to a positive solution of the challenges brought up. In other cases, confidential advisors, the Ombuds Officer and other parties (e.g. HR) were consulted. For confidentiality reasons, however, only generic information is available to the Faculty in this regard. The Faculty is in close contact with the university support services to improve the yearly reports of the Confidential Advisors and Ombuds Officer, and more information will become available in future.

Various activities (for instance a comprehensive buddy system with staff members supporting PhD candidates with conversations, visits etc.) were developed during the COVID pandemic to minimise the negative impact of (partial) lockdowns. While the Faculty was never closed completely, accessibility especially of laboratories was restricted, leading to additional stress and delays.

PhD welfare is seen as a collective issue in which also staff members can have a role. A course on Non-Violent Communication has been offered to staff members of all departments with the underlying idea that improved communication can make relations between PhD candidate and their supervising team easier (see chapter 4). The general topics of PhD welfare and of undesirable behaviour are now firmly on the agenda of the Faculty, of the departments and of the various Faculty organizations.

The Covid pandemic resulted in delays for a considerable number of PhD candidates, in particular for those performing laboratory work or field work. If possible, within Covid regulations, lab work was continued but external factors (delayed material, supplies, etc.) often hampered progress. Moreover, physical problems (Covid infections) and social problems (loneliness, isolation, concern about family members) took their toll, especially amongst foreign nationals. The Faculty's response has been to:
1) stimulate various measures within departments to organise on-line events for PhD candidates and to maintain (on-line) contacts between PhD candidates and supervisors,
2) stimulate PhD supervisory teams to reassess/reduce scope and deliverables to cope with these unforeseen Covid-related setbacks, and
3) provide financial means (partly from Faculty budget, partly from central funds) to grant extensions, typically for three months.

Requests for Covid-related extensions were prepared by departments (requiring motivation and explanation if/how scope/deliverables can be reduced) and discussed during the bi-weekly Faculty MT Meeting. In the period December 2020 – May 2023 a total number of 85 extension have been granted.

3.6.3 PhD Empowerment

The Faculty supports and promotes the development of individual PhD candidates and PhD candidates as a group. Initiatives such as the PhD council at Faculty level or involvement of PhD candidates in decision making at department level, are good examples of our support. The PhD council is functioning well. It has organised Faculty-

[22] Survey Evaluation PhD Candidates, 2022/2023; no quantitative information is available on the impact of COVID on these numbers.

wide events, surveys among PhD candidates (for instance on welfare during the pandemics and on the impact of publication policies on PhD duration) and more specific activities at department level. The council meets regularly with the FGS director and with the Dean.

Within departments, PhD candidates have also become quite active, forming department councils and being involved in the decision-making process of their departments in different forms (see chapter 4).

3.7 Strategy for the next six years

Table 9 SWOT analysis PhD policy and training.

	Strengths	Weaknesses
Internal view	• General, Faculty-wide acknowledgment of the importance of PhD candidates for the Faculty. • Increasing awareness at Faculty and department level of the need to tackle the issue of long duration of PhD projects. • Strong involvement of PhD candidates, especially well-functioning PhD council. • Strong support from support office (FGS). • Strong coordination and synergy with the University Graduate School (at least in terms of policy development) and with the directors of other Faculty Graduate Schools.	• A significant number of PhD candidates experience too high stress and pressure levels, which impact their welfare and performance. Part of this is associated with the excessively long duration of PhD projects (see Chapter Academic Culture). • The support & report system is not always visible and accessible and weakly accountable. This impacts the trust PhD candidates have in the university for support. • The different services involved in PhD welfare do not share enough of their findings among each other nor with the Faculty, which prevents a systematic approach to solve criticalities. • There is no specific Doctoral Education policy dedicated to contract PhD candidates and it is unclear if they should be judged for the level they have or the growth they have experienced. • Most of the services receiving reports on conflicts and/or undesirable behaviour, operate on the basis of mediation. When there is a strong power dependence (like between PhD candidate and supervisor) this can be problematic, and cases remain unsolved. • The general, high-level issue is that the broad awareness of the challenges experienced by PhD candidates raises expectations and hopes that need to be met in the very near future. If this does not happen, PhD candidates will feel frustration and lack of trust in the ability of the Faculty/ university to provide solutions. • This can make the Faculty less attractive for potential PhD candidates and discourage internal PhD candidates to continue on an academic career.
	Opportunities	**Threats**
External view	• Decreasing the excessive PhD duration can lead to a substantial improvement of PhD welfare. • Improving coordination among individuals and organizations working on PhD welfare can allow for improvements in working conditions (see Academic Culture). • Developing a well-functioning support/ report system can improve (the reputation of) the Faculty and strengthen its position in the world.	• Discussions on work pressure and, even more so, on undesirable behaviour and harassment are actively ongoing in Dutch society, implying highlighted attention of the media for what is happening in universities and at TU Delft. (see Academic Culture).

The next six years will be of great importance in the PhD domain. Topics such as PhD duration, welfare and support are now widely acknowledged and discussed in the Faculty, which raises expectations among PhD candidates and staff that need to be satisfied. Based on the above SWOT analysis (see Table 9), three priorities for the future arise.

3.7.1 Reducing PhD duration

While there has been progress in selection and supervision and, at least in some departments, in PhD performance (the number of PhD candidates finishing within five years), we are still substantially below the level where we would like to be. There are multiple reasons behind excessive PhD duration, and the strategy to tackle this is therefore multifaceted:

a) Selection interviews will include better alignment on PhD duration and expectations of the supervising team (for instance on publications).
b) PhD candidates who started before 2012 (when the Graduate School was founded) will be de-registered unless they present a convincing plan to finish their thesis.
c) A stricter approach is under discussion according to which all PhD candidates apply at the end of their 4th year and who have not submitted their thesis are required to present a detailed plan documenting their progress and their ability to submit the thesis draft during the 5th year. Except for those affected by special circumstances (illness, parental leave, etc.), PhD candidates will be de-registered from the Graduate School if no plan is submitted and if their plan is not implemented.

A special policy will be defined for “contract-industry-PhD candidates”, that is, PhD candidates who are not employed at TU Delft and carry out their PhD while working at knowledge institutions or in industry. In particular, these guidelines should provide a frame defining the Doctoral Education program they need to fulfil and the expected duration of their Thesis.

3.7.2 Improving supervision

We will invest in the generation of new staff members providing them information and training on PhD supervision. This will take place through:

a) Regular introductory meetings between FGS and new hires.
b) Update of the University Teaching Qualification (UTQ) program which, at the moment, has no specific module dedicated to PhD supervision.

3.7.3 PhD welfare and support in the case of undesirable behaviour

At this moment, the support & report system is characterised by a large number of services that are often poorly visible, have an unclear mission and workflow, and weak to no measures on accountability and transparency. Only some of these services provide a yearly report of their activities indicating, among other things, how many cases they received, how many were solved and what the satisfaction of the applicants was. Insufficient transparency makes these services poorly accountable and does not favour trust of PhD candidates in the system. In coordination with the University Graduate School and the University Diversity & Inclusion Office, we will strengthen this system as follows:

a) We will develop an updated overview of support & report services, including how they can be reached, their goals, workflow, record, etc.
b) On this basis, we will develop a plan to make the system more visible and efficient and investigate if new entry points are needed.
c) We will develop a Faculty platform for the support & report services to communicate with each other and with the Dean, the Faculty Graduate School and other relevant parts of the organisation. During this meeting, experiences will be shared to identify structural problems and suggestions will be made to strengthen welfare policies.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4. Academic Culture

4.1 Introduction

In this chapter we will present a self-evaluation of the Academic Culture within the Faculty of Civil Engineering and Geosciences, describing achievements as well as goals and challenges. In the SEP 2021-2027, academic culture is divided into two subthemes: (1) openness, (social) safety and inclusivity and (2) research integrity. For our analysis, we have also adopted this distinction, and separate sub-sections are devoted to each of the two themes in sections 4.2 and 4.4-4.7 of this chapter.

In the SEP 2021-2027, the subtheme 'diversity' is part of HR Policy, and it is therefore addressed in chapter 5 of this self-evaluation report. Certain aspects of diversity are naturally part of a discussion on academic culture and will also be discussed in the present chapter.[23]

At TU Delft, diversity, inclusion, social safety and research integrity are addressed – both in terms of policy and accountability – by multiple actors, including line management, the Executive Board, the Diversity & Inclusion (D&I) Office[24], Faculty D&I Officers, the Integrity Office,[25] Faculty and departmental MTs and HR. A dedicated D&I infrastructure, which branches out from the central university level into the faculties, initiates and supports policy initiatives. This chapter focusses on university- and Faculty-wide policies, where the emphasis for university-wide policies is on their implications at Faculty level. Detailed information on individual departments can be found in the corresponding chapters. This chapter was written with contributions from the Faculty D&I Officer and the Faculty D&I Team (related to openness, (social) safety and inclusivity) and by the Faculty's Executive Secretary (related to research integrity) in close cooperation with Faculty and university support staff.

4.2 Mission and strategic aims of the past six years

4.2.1 Openness, (social) safety and inclusivity

Triggered by the increasing awareness of the importance of diversity and inclusion in the Netherlands and elsewhere, TU Delft appointed one of its professors as the first Chief D&I Officer in 2020, supported by a new D&I Office (Figure 13). At TU Delft and Faculty level, there was an increasing need to address issues related to diversity, inclusion, and academic culture in general; surveys of staff well-being (Medewerkersmonitor), for instance, highlighted issues related to undesirable behaviour. Similarly, there was a growing awareness indicating that the excessive duration of PhD projects was partly related to D&I issues (see also chapter 3).

[23] In its 'Vision on Integrity 2018-2024', TU Delft introduced an infrastructure composed of three (interrelated) pillars: academic, social and organizational integrity. The first pillar covers integrity and ethics in both education and research. The second refers to policies and practices related to social safety and undesirable behaviour. In the third pillar, the focus lies on topics such as good governance, responsible cooperation with third parties, and prevention of conflicts of interests. Combined, these three pillars cover many of the topics listed under the umbrella of Academic Culture in the SEP 2021-2027.

[24] https://www.tudelft.nl/en/about-tu-delft/strategy/diversity-inclusion

[25] https://www.tudelft.nl/en/about-tu-delft/strategy/integrity-policy

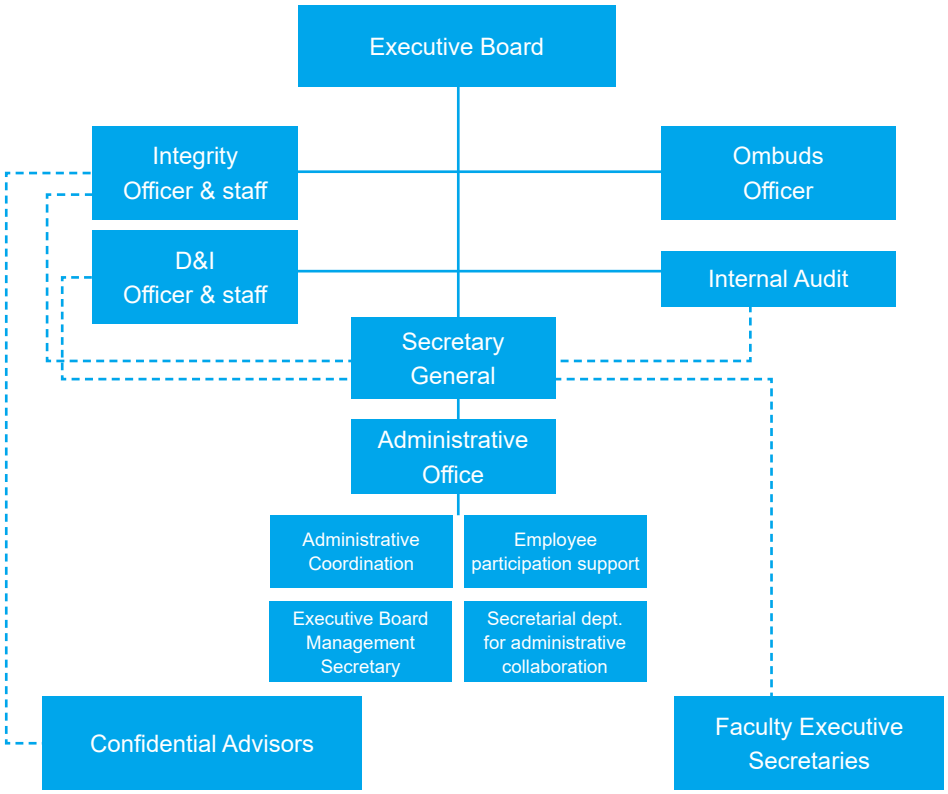


Figure 13 Organisational chart showing the embedding of the D&I Office and the Integrity Office at TU Delft level.

The D&I Office developed general guidelines for a wide range of activities, but no clear goals were defined yet. Its primary mission was to evaluate and improve the academic culture and to install a similar structure at Faculty level that would help implement processes. The Faculty appointed a Faculty D&I Officer in 2021 to liaise with the university D&I Office supported by a Faculty D&I Team from 2022 (Figure 14). At the start, no clear mission statement or strategic aim was defined. In recent years, important headway has been made to raise awareness levels and update reporting and complaints procedures at University level. However, there remains work to be done.

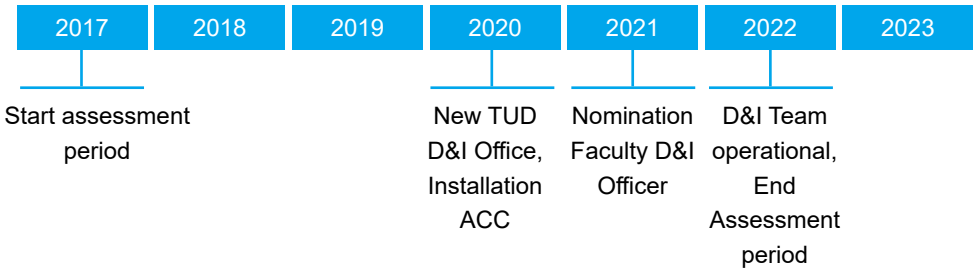


Figure 14 Timeline of D&I milestones in the Faculty of Civil Engineering and Geosciences.

4.2.2 Research integrity

In 2018, the Committee Reassessment Integrity Policy was installed by the Executive Board of TU Delft. It was asked to present recommendations for a well-structured integrity policy, as existing committees, regulations, procedures, and Confidential Advisors formed a patchwork that was neither easy to grasp for students nor for staff. The resulting Vision on Integrity 2018-2024 is part of the implementation agenda of the TU Delft Strategic Framework 2018-2024.

The Committee recommended inclusion of a TU Delft Integrity Statement in the TU Delft Code of Ethics 2012 and to transform it into a TU Delft Code of Conduct. It further proposed a new integrity infrastructure (partly based on the existing one), based on three pillars: academic, social, and organizational integrity. Deliverables were divided over four working agendas, including proposals to invest in awareness programmes, strengthen the communication strategy, professionalise the team of Confidential Advisors, and evaluate a pilot project for an Ombuds Officer for staff. Zooming in on research integrity, the committee made recommendations on a variety of topics, such as data management policies, human research ethics infrastructure, complaints procedures, and training for research staff, postdoc's, PhD candidates and students. To help achieve this, on both TU Delft level and within its faculties and support services, TU Delft established an Integrity Board (which functions as a steering committee and reports directly to the Executive Board) and an Integrity Office (Figure 13). The chair of the Integrity Board acts as TU Delft's Integrity Officer.

4.3 Follow up from previous assessment

Starting from the SEP 2021-2027, academic culture became a key component of the research assessment. The SEP 2021-2027 was used as the basis for the Midterm Research Assessment Civil Engineering 2017-2020. In response to this, two recommendations related to openness, (social) safety and inclusivity were made:

1) Include junior staff in strategic planning and improve transparency in decision making at MT-level.
2) Continue the Academic Culture Committee (ACC; see section 4.4), which was formed by the Faculty in preparation for the Midterm report, as an organisational component of the Faculty.

In addition to these recommendations, the ACC itself made important recommendations, which were shared with the Faculty Management Team. The follow-up to the above recommendations will be addressed in section 4.4, as they are so intertwined with the strategic process during the assessment period. No specific recommendations were made related to research integrity in both the Research Assessment Civil Engineering 2011-2017 and the Midterm Research Assessment Civil Engineering 2017-2020.

4.4 Strategic process of the past six years

4.4.1 Openness, (social) safety and inclusivity

The new SEP and the Mid-term Research Assessment (2017-2020) led to the formation of the Academic Culture Committee (ACC) by the Faculty. The ACC's objectives were threefold:

1) To assess the daily practice of the research units with respect to diversity, openness, social safety, and research integrity.
2) To provide an analysis of existing bottlenecks.
3) To formulate general measures to improve academic culture in the Faculty.

To address these, the ACC presented a report to the Faculty MT in the spring of 2021, which was unanimously considered to be an important starting point for future improvements. The Faculty installed a Faculty D&I Officer in 2021. After the Midterm Research Assessment, a Faculty D&I Team was installed to support the Faculty D&I Officer and to continue the initiative behind the ACC. Its role was defined in its Terms of Reference. The formal goal of the Faculty D&I Team is to provide advice, either on request or on its own initiative, to the Faculty Management Team and the Dean aimed at making make the Faculty a more inclusive and diverse organisation.
The Team is composed of the Faculty D&I Officer, an HR representative, a member of

each department, and a chair. The Faculty D&I Officer/Team can be invited or ask to be invited to Faculty MT meetings.

The D&I Team defined initial goals and provided the following advice:
- Carefully consider ways to make the Faculty hierarchy and decision-making processes more transparent.
- Organise events to increase awareness of (lack of) social safety in the Faculty.
- Professionalise recruitment processes in view of implicit bias (see chapter 5).
- Make diversity visible and recognizable, especially in decision-making bodies (see chapter 5).
- Set goals, collect data, and examine change over time and in comparison to other universities and organisations.
- Appoint a Confidential Advisor for the Faculty of Civil Engineering and Geosciences and communicate clearly to the community how the advisor can be contacted and what their role is. This goal has been reconsidered in light of a university-wide evaluation of the structure of the team of Confidential Advisors. Confidential Advisors are now provided at university level.

4.4.2 Research integrity

At Faculty level the main activities related to the implementation of the Vision on Integrity 2018-2024 were focused on raising awareness, and the Faculty followed initiatives led at university level[26]. The ACC also made recommendations related to research integrity during the Midterm Research Assessment:
- Provide more training of staff on research integrity issues.
- Address research integrity issues (such as conflicts of interest) in regular R&D meetings.
- Raise awareness of research integrity through widespread communication.

The various aspects of research integrity are best reflected through the TU Delft Leadership Profile:
1) Personal leadership – Personal Leadership focuses on an intrinsic drive to do the right thing, supported by standard processes within the TU Delft such as the application process of the Human Ethics Research Committee for research involving humans, procedures on Open Science to provide, for example, FAIR data (see chapter 2), or HR-training/onboarding. Personal leadership is shaped by more than following training alone and can also be reinforced by feedback as part of the supporting processes, for example advice received in the case of investigations by the Academic Integrity Committee, Conflict of Interest Committee, the Integral Safety and Security Office, or related to external (non-) peer review.
2) Leading a project/programme/team – This reflects the role of a scientist leading others on research integrity. It comprises the elements of personal leadership, guiding colleagues to and through procedures, committees, etc., discussing choices and/or giving feedback, but also more formally, addressing issues such as the outcome of a compulsory plagiarism check for a PhD thesis. All PhD theses are checked and discussed with PhD candidates by their supervisor.
3) Leading an organisation – This reflects the role of line management in discussing dilemmas, annual reports, for example by the Confidential Advisors, and the research integrity system at Faculty level. Openly discussing research integrity helps to raise awareness within the Faculty and department MTs of procedures and their importance. Within the Faculty, ancillary activities (Dutch: nevenactiviteiten) are reviewed annually.

[26] Besides the TU Delft Code of Conduct, the following policies are in place at TU Delft: (1) The Netherlands Code of Conduct for Research Integrity 2018, which applies to all researchers of TU Delft and which will be revised in 2023-2024; (2) The TU Delft Regulation on Complaints about Research Integrity, which will be updated in line with a modification of the National Format for Regulations on Complaints about Research Integrity 2023; and (3) The European Code of Conduct for Research Integrity, which was revised in 2023.

4.5 Evidence

We have monitored our progress on various aspects of academic culture, and distinguish the following types of evidence:

- Openness, (social) safety and inclusivity:
  - Initiatives to make the Faculty hierarchy and decision-making processes more transparent.
  - Organization of events to increase awareness of (lack of) social safety in the Faculty.
  - Reporting of undesirable behaviour.
- Research integrity:
  - Providing more systematic training of staff on research integrity.
  - Addressing of research integrity issues.
  - Raising awareness of research integrity through widespread communication.
- Monitoring academic culture

4.6 Accomplishments during the past six years – research quality and societal relevance

4.6.1 Openness, (social) safety and inclusivity

Transparency of Faculty hierarchy and decision-making processes

The process described in chapter 1, section 1.4.5 describes a change in the organisational structure and culture of the Faculty during the assessment period partly related to the recommendations of the ACC. These changes reflect the desire for increased transparency expressed by staff. In the different chapters of the departments, changes in structures and procedures to improve transparency in the departments are explained. These changes relate to the flow of information and involvement of (early-career) staff in decision making; they are different for each department (see Appendix C1, table 43 for an overview of involvement of early-career staff in decision making across the five departments). The Department Organisational Principles (DOP), set by the Faculty MT, guide the management structure of the departments, allowing flexibility where possible while setting clear boundaries where necessary.

Building on the improved organizational structure, the Faculty aimed to stimulate an open, inclusive environment by increasing the transparency of several internal processes. To ensure non-biased selection of new staff, the recruitment process was thoroughly revised, amongst others by requesting at least 50% female candidates amongst the candidates selected for an interview, identical questions to each candidate to allow for a fair comparison of responses and independent assessment of each candidate by individual committee members. Several applications of this new process in practice have confirmed its value, revealing a much more open discussion amongst committee members during the final assessment of all candidates. Within departments, organizational roles and (external) nominations are increasingly announced and filled in by means of open invitations for expressions of interest to all staff. This was found to work well for several internal roles (track coordinator, committee membership) but also for external representation. The open and transparent approach was found to offer an excellent platform for staff to express interests and demonstrate ambitions, thus shaping individual careers in a positive manner. Notwithstanding these positive developments, their level of implementation still varies strongly between departments and leaves considerable room for further improvement.

Organisation of events to increase awareness on (lack of) social safety in the Faculty

Against the background of the intensifying discussion on undesirable behaviour in Dutch society, the Faculty has seen a strong increase in activities related to academic culture

over the last few years. These activities resulted from various initiatives launched in different parts of the Faculty. A stimulating example is given by a lunch session organised by the department of Hydraulic Engineering, where permanent staff as well as PhD candidates and postdocs were asked to reflect and exchange thoughts on a list of D&I statements. Other departments (for instance Transport & Planning and Engineering Structures) are also developing comparable initiatives. Various surveys have shown that social safety is a relevant issue across the whole Faculty. Following the example of the department of Geoscience and Engineering, a course on Empathic Communication is being offered to the academic staff of all departments.

Reporting of undesirable behaviour

Incidence of undesirable behaviour is very likely underestimated by official annual reports, partly because an integral overview of all incidents reported to the TU Delft Confidential Advisors and Ombuds Officer is not yet available. The Faculty has given this as feedback to the Integrity Office in addition to suggestion to further improvements.

4.6.2 Research integrity

Systematic training

The TU Delft Leadership Profile defines six components of which one is focussed on Integrity and Trust. The profile is the basis for leadership training programmes. New PhD candidates and Tenure Track (now Academic Career Track) staff respectively start with the PhD start-up programme or the Personal Development Programme as part of the onboarding programme. Line management can address research integrity in the context of the annual Result & Development (R&D) meetings. There is no monitoring in place whether new staff have followed training.

Addressing research integrity issues

Within the TU Delft, research integrity issues are discussed at different levels:

- Between junior scientific employee (PhD candidate/postdoc) and promotor/supervisor – In this case, the supervisor gives informal (e.g. feedback from a HREC[27] -application) or formal feedback to the employee (e.g. from a plagiarism check) with the goal of helping and supporting the employee in their development. This information is not systematically available.
- Between early-career or senior scientific employee and line management (Section Head, Department Chair, Dean) – In this case, line management is involved and/or informed of a formal step taken to report the issue to a committee such as the Academic Integrity Committee. The outcome of the process can be an action of the employer towards the employee. The annual reports of the Confidential Advisors give an overview of the number of issues in various categories.

Raising awareness of research integrity

Openly discussing research integrity is promoted within the Faculty. Leadership training, discussing research integrity in R&D-meetings, discussing cases/dilemmas within MTs are examples of such discussions. Availability of this information is limited, or the information is only available at university level. At TU Delft level, the Integrity Board plays an important role in distributing lessons learned from Advisory Opinions by the LOWI (the national research integrity board), specifically in cases in which TU Delft was/is involved, in order to prevent possible violations of research integrity standards in the future. The same holds for the Policy Officer Academic Integrity, who tracks international developments to see what TU Delft can learn from its international counterparts.

27 Human Research Ethics Committee

4.6.3 Monitoring academic culture

The wealth of initiatives taking place in the domains of diversity and inclusion, social safety and (research) integrity is a very positive result and documents the growing awareness of the importance of academic culture. The effectiveness of these initiatives is difficult to assess, both on a process and on an outcome level. In part, this is because academic culture is hard to measure directly. On the other hand, metrics on the degree of participation in certain trainings are available, and guidelines have been issued to discuss inclusion and research integrity in R&D meetings. Management reports and actions in response to undesirable behaviour could be registered, monitored, and reported and, in doing so, lead to information to improve academic culture. Ongoing data collection, together with the formulation of clear goals are needed to allow for in-depth analyses on trends in academic culture. The most extensive dataset is on gender (see chapter 5). As an example, Table 10a and b show the (limited) data on research integrity that can be drawn from the annual reports of the TU Delft Confidential Advisors (2022). The fact that this now includes data on research integrity and not just social and organisational integrity is a positive development.

Table 10 Data on research integrity from Annual Report (2022) of the TU Delft Confidential Advisors, a) on university-wide level, b) per faculty/subdivision.

a) Reports and advisory meetings on academic integrity	2022
Reports of possible violations of academic integrity	8
Other notifications and follow-up meetings with reporters	17
Total	**25**

b) Origins of reports and notifications			
Faculty/Business unit	**Staff member**	**PhD candidates**	**Student**
A&BE	1	1	
CEG	3	2	2
EEMCS	3	1	
IDE			
AE	2	1	
3mE	1	1	
TPM		2	
AS	2		
University Services/Other	2		1
Total (25)	**14**	**8**	**3**

4.7 Strategy for the next six years

To help formulate the strategy for the next six years, Table 11 presents a SWOT analysis of academic culture in the Faculty. We emphasise both the risks negative aspects of academic culture can pose for the quality and societal relevance of the Faculty's research, and the opportunities offered by improving academic culture. A strategy for the future relies on the interconnection between multiple actors and policies on TU Delft level and within the Faculty. To systematically address the various aspects of academic culture we will make use of the Risk Inventory and Evaluation (RI&E) process that is currently ongoing in the Faculty. The RI&E process addresses physical safety, health and wellbeing in a systematic management system (following the Plan-Do-Check-Act cycle). This includes setting strategic aims for the organisation, defining responsibilities

and policies, setting training requirements and targets and means of monitoring those. Furthermore, internal communication and creating awareness are important components of the RI&E process. The existing three-yearly cycle around the formal Employee Monitor questionnaire, which includes the definition of action plans at department and Faculty level and formal agreements with the Executive Board should be aligned with this RI&E process. The Faculty D&I Team will be involved in this policy-making process. The final aim will be to develop a more systematic framework for addressing, monitoring and reporting of issues related to academic culture.

Table 11 SWOT analysis Academic Culture.

	Strengths	Weaknesses
Internal view	• The Executive Board of the university is strongly engaged in Academic Culture issues. The new D&I central office now has substantial staff and is very active. • Within the Faculty, there is an increasing reflection on our ways of working and behaviour and growing activity to develop more open, transparent, and inclusive procedures. • A Faculty D&I Team has been established and has, via the Faculty D&I Officer, monthly meetings with the Dean on D&I-related issues and initiatives. • A substantial number of Entry Points in the Integrity Roadmap exists, with motivated staff, dedicated to the wellbeing and safety of staff members	• Although various aspects of Academic Culture are being increasingly addressed, a framework to systematically manage these aspects is not in place. • As a result, strategic goals are missing while procedures, training, monitoring requirements etc. are only developed to a limited extent. • Awareness of the various Entry Points in the Integrity Roadmap is limited amongst staff, and access can be further improved. • Discussions regarding diversity are presently mostly focused on gender with limited attention to wider aspects of diversity. • Yearly reports of Entry Points suggest strong underreporting of incidents. • The D&I Team lacks secretarial support. • The Faculty has no professional D&I advisor.
	Opportunities	**Threats**
External view	• Academic Culture with its various subthemes (D&I, Integrity, etc.) is clearly a hot topic and is high on the societal and University agendas. • The experiences and increased awareness gained from working with new, open processes offer valuable input for the formulation of Faculty policies on AC and D&I • The ongoing RI&E process provides a framework for systematic management of various aspects of AC and D&I. • The D&I Team can play an important role in the development of such a systematic management approach to AC and D&I. • A stronger Academic Culture can play a major role in attracting talent worldwide. • Sharing of good practices amongst departments and incorporating learnings from other faculties can speed up the improvement process.	• Early-career hires are at risk of being subject to very high workloads with little support, increasing the chances of burn-out. • The power distance between senior and early-career academic staff (notably supervisor and PhD candidate) remains a risk factor and may increase because of the growing cultural diversity of our staff. • Serious incidents of undesirable behaviour are not only harmful to the people involved but may also seriously damage the reputation of the Faculty/ university.

Research integrity

In the past years, the Vision on Integrity 2018-2024 has helped to improve TU Delft's integrity infrastructure. However, a lot of work remains to be done, especially in terms of restructuring and strengthening reporting and complaints procedures, raising awareness, supporting line managers in performing their integrity tasks and gathering and sharing relevant management information. In 2023, the Executive Board approved a proposal to have the university's integrity system evaluated by external experts. The outcome of this analysis may serve as a basis for evaluations of the Integrity Office, the D&I Office and the Ombuds Officer as well as for a new Vision on Integrity, to be implemented from 2025 onwards. The Faculty will liaise with the D&I and the Integrity Offices to:

- Adapt the Annual Reports towards integration of all elements in line with the Integrity Roadmap.
- Request integral analysis and feedback to line management of cases and trends and offer the possibility to – at least once a year - discuss these trends within the Faculty MT.

We will also focus on training and raising awareness on organisational level.

Training

Training research staff is a priority in the Vision on Integrity. We will follow the TU Delft Leadership Profile in the implementation of this. At all levels (individual, leaders of projects/programme/ teams and leaders of organisations), basic knowledge of research integrity within TU Delft should be provided. Although research integrity is the subject of international standards (peer review, FAIR, etc.), the procedures and committees are local and can differ from previous employers. During onboarding and (leadership-)training, this knowledge must be transferred.

Raising awareness

TU Delft has strong procedures and an integrity infrastructure, which is – at this moment – focussed on a case level. Lessons could be learned, and recommendations could be made based on trends that emerge from all these cases, which does not happen now. We propose the following initiatives:

- *Discussing cases MT level* – In addition to the discussion of ancillary activities the (Faculty) MTs should discuss more systematically dilemmas that arise (e.g. in the form of a moral deliberation), annual reports on integrity or other input received from the central university.
- *Guidelines for line management* – Line management has a formal responsibility for research integrity and for developing their employees in a broad sense. They are also responsible for formal feedback including as part of the R&D cycle. Guidelines will be developed to facilitate managers in this task (to guide, support, act and ultimately to enforce) and to encourage early intervention.
- *Introduction of Moral Deliberation at Faculty level (Dutch: moreel beraad)* – An increasing number of (moral) dilemmas are being discussed through a so-called moral deliberation at TU Delft level, including dilemmas related to research and organisational integrity. The Executive Board have highlighted several topics that deserve special attention in 2023, including knowledge security and collaborations with the defence and fossil-fuel industries. To structure discussions and clarify viewpoints, dilemmas, and ways forward, a standard model of moral deliberation has been introduced, which will be transferred to Faculty level in the upcoming period.

5. Human Resources Policy

5.1 Introduction

HR policy is set at two main levels: at the level of the central university (hereinafter, TU Delft level) and the level of the Faculty of Civil Engineering and Geosciences (hereinafter, the Faculty). The departments are responsible for the implementation and execution of these policies. At TU Delft level, Human Resources (HR) is one of the so-called University Services that the University Corporate Office provides to its Faculties. University Services provides support for the primary processes (research, education, and knowledge transfer), organises the administrative processes and coordinates central policy processes. University Services delegates HR teams to the Faculties. The HR team of the Faculty consists of five HR advisors and an HR Manager (5.2 FTE). The HR team supports and provides advice on the implementation of the policies and advises the different supervisors in the Faculty (including the Dean, the Faculty Management Team, Department Heads and Departmental Management Teams)[28]. So, the responsibility for the execution of HR policy lies with the Dean and the supervisors. HR's administrative processes are organised at TU Delft level by the HR Service Centre.

Focusing on talent management and diversity as HR policy's two key components (SEP 2021-2027), this chapter will provide and describe a self-assessment of HR policy within the Faculty as embedded within TU Delft-level HR policy for the period 2017-2022. Inclusivity is discussed in chapter 4, while chapters 6-10 focus on department-specific HR policies and their implementation and where they deviate from or are complementary to Faculty policy described in this chapter. This chapter has been written by the Faculty's HR Manager and one of its HR advisors.

5.2 Mission and strategic aims of the past six years

HR policy's underlying mission and strategic aims at Faculty level are described in the Faculty Strategy (2019-2024), which is embedded in the TU Delft Strategic Framework (2018-2024) and the TU Delft Long-term HR Agenda (2018-2024).

5.2.1 TU Delft Strategic Framework and TU Delft Long-term HR Agenda (2018-2024)

TU Delft works towards solving global challenges by educating new generations of socially responsible engineers and pushing the boundaries of technical sciences. This vision leads to the following mission for talent management:

[28] In this chapter, two terms/roles are defined as follows: (1) Academic staff: Assistant, Associate and Full Professors, and Researchers (formally, this category also includes Lecturers, but they are not in the scope of the Research Assessment); and (2) Supervisors: includes the Dean, departmental supervisors (chairs, section heads, and supervisors with a formal organisational management task but who are not called section heads).

To develop and enhance the expertise of leaders in tomorrow's technology and provide professional, high-quality and ethical engineering education throughout their careers. We continuously improve our collective effectiveness, performance and organisational resilience by embracing professionalism, collaboration and openness as guiding principles.

Regarding diversity and inclusivity, TU Delft's mission is as follows:

At TU Delft, we believe in embracing diversity and creating an inclusive environment. We follow the Universal Declaration of Human Rights, which states that all human beings are born free and equal in dignity and rights. We recognise and respect differences in socio-economic, cultural or religious backgrounds, nationality, gender, sexual orientation, age, physical appearance, and roles and positions. We believe that diversity adds value to our community and promotes different perspectives and ideas.

TU Delft endorses the principles of the European Charter for Researchers (HR Excellence in Research) and the European Code of Conduct for the Recruitment of Researchers.

To realise its mission, the TU Delft Long-term HR Agenda (2018-2024) identifies three strategic aims:
1. Attracting and retaining ambitious and talented staff.
2. Encouraging and appreciating the talent development and sustainable employability of staff.
3. Offering staff, a safe, challenging, and meaningful work environment.

5.2.2 Faculty Strategy (2019-2024)

The Faculty Strategy (2019-2024) sets as its mission to be the employer of choice for all staff and distinguishes three strategic aims (so-called 'changes themes') that pertain to talent management and diversity:

SA1 Improve recognition and rewards for groups and individuals.
SA2 Provide an environment for individuals to grow.
SA3 Improve diversity (this chapter) and inclusivity (see also chapter 4).

Its mission requires the Faculty to provide opportunities comparable to other renowned universities worldwide, develop leadership capabilities in its academic staff, and offer transparent and flexible career paths for scientists while ensuring a healthy work-life balance and a fair distribution of workload.

5.3 Follow-up from previous assessments

As part of the Research Assessment 2011-2016 and the Midterm Research Assessment 2018-2020, the following three recommendations were received and have been addressed as follows.

First, the tenure-track process has been made more transparent and balanced. The Faculty is proud of the way the discussion on this issue was initiated. In the period 2018-2020, meetings with tenure-track Assistant Professors were organised following a letter written by early-career staff to the Dean and the Faculty Career Development Committee (CDC) that raised concerns regarding the Faculty CDC. This letter was a wake-up call for the Faculty CDC. A meeting in March 2020 between two representatives of the early-career staff, section heads, department chairs, the Dean, and the chair of the Faculty CDC resulted in the following intentions to review the Faculty tenure-track policy:
- Investigate opportunities to revise the 5-(plus 1) year tenure-track contract.
- Communicate that the tenure track is a development track related to lifelong learning.

- Revise the Faculty tenure-track criteria and adapt these to be compatible with the *Recognition and Rewards* programme of the Universities of the Netherlands (UvN).
- Align the annual performance review cycle (R&D cycle) meetings between staff and their supervisors with the tenure-track recommendations made by the Faculty CDC.

As a result, the tenure-track criteria were reformulated in a collaborative effort between the parties above. Each new tenure-track Assistant Professor receives the criteria, which are discussed and assessed during the annual 'Result and Development' (R&D) cycle. The Faculty CDC's recommendations are now also explicitly discussed during the annual performance review meetings of the whole R&D cycle within the departments. These meetings are attended by the supervisors of the department, the Dean, the Director of Education, the HR Manager and the departmental HR advisor (but not the staff members themselves). This enables supervisors, the Dean and HR to follow the development of the individual staff members, thus ensuring transparent and fair career opportunities supported by the Faculty CDC.

The Faculty also started to write a new tenure-track policy with much more focus on development, moving from a 'track to become tenured' to a 'development track'. During this same period, TU Delft initiated a TU Delft-wide evaluation of the tenure-track policy. Because the Faculty had a relatively large role in this evaluation, the Faculty writing process was put on hold pending the outcome of this evaluation. This evaluation led to a revision of TU Delft's tenure-track policy (the new Academic Career Track Policy, active from May 2023) that was in line with the Faculty's vision.

Second, the Faculty was encouraged to put workload and hiring of new staff members in a broader perspective since hiring might also lead to more competition, both internally and externally, for the limited research funding available and does not always contribute to reducing workload. The Faculty has taken three measures to address work pressure:
- In the Faculty career criteria for Assistant Professors, the criterion 'has achieved funding' has been replaced by 'has pursued research grants as main applicant'.
- A start-up package now provides a fully funded PhD position for each newly appointed tenure-track Assistant or Associate Professor. This measure also contributes to being a competitive employer in the international labour market.
- Embracing the *Recognition and Rewards*[29] programme of the Universities of the Netherlands (UvN) moves attention away from only funding acquisition and H-index etc. when rewarding career development.

Third, the Faculty has been strongly encouraged to also increase the gender balance in its higher ranks. During the assessment period, the Faculty has attempted to recruit experienced female candidates for higher-ranked positions, including through the Delft Technology Fellowship programme. The Faculty has engaged recruitment agencies to identify female candidates for higher-ranked positions. Two candidates did apply, one for a Full Professor position and another one for an Associate Professor position. In these two instances, unfortunately, both candidates opted for alternative positions owing to personal circumstances, despite the Faculty doing its utmost, including offering access to the TU Delft spousal hiring programme and other support, including with finding housing. As an alternative strategy, the Faculty has therefore focused on developing its existing pool of female talent towards the next steps in their career within the Faculty.

[29] https://recognitionrewards.nl/

5.4 Strategic process of the past six years

This section describes what has been done during the assessment period to achieve the three strategic aims of the Faculty (SA1-SA3).

5.4.1 Recognition and Rewards (SA1) and Environment to Grow (SA2)

Several strategies have been implemented to simultaneously achieve SA1 and SA2.
First, as Recognition and Rewards start with attracting and retaining ambitious and highly talented staff, the Faculty has professionalised its recruitment process, developing a standardised process for selection committees and setting requirements for the (female) membership of selection committees.
Second, based on the UvN's *Recognition and Rewards* programme and its *Room for Everyone's Talent* position paper (November 2019), the following aspects have been incorporated into the Faculty career criteria:

- Both individual output and ability to work together in teams.
- A candidate can excel at an individual criterion and, in so doing, compensate for performance in other criteria, provided these other criteria are met at a basic level.
- Within the Academic Career Track it is now possible to be promoted to Associate or Full Professor level with a primary focus on education instead of research (since February 2019). Two Assistant Professors in the Faculty have been promoted to Associate Professor with such a primary focus on education.
- Internal performance-based promotion to Full Professor (governed at TU Delft level) became possible in 2017 and replaced the traditional system of a limited fixed number of Full Professors ('chairs'). This has improved the career perspectives of academic staff. During the assessment period, six Associate Professors have been promoted to Full Professor (three male, three female).

The Faculty recognises the relationship between these changes to its career criteria and diversity: differences are allowed to exist; not everyone must fit the same mould. These changes make room for flexible career paths. At the same time, some colleagues find this flexibility difficult for reasons of transparency. The results and speed of career growth depend less on a 'box-ticking' type of list in terms of easily quantified criteria, such as H-index. The Faculty career criteria must be assessed holistically in qualitative terms.
A cautionary note is required: these new career criteria require maturity and self-reflection from the candidate seeking promotion and from the supervisor giving feedback. To address this, staff members are supported by various training courses, including R&D training, feedback training and leadership training.

Third, the annual R&D cycle, the importance of which has been underlined by the above, puts particular emphasis on:

- The development of staff and courses or coaching that can support this.
- Rewarding individual staff or the group that has shown initiative and has taken responsibility to get the best out of themselves and others.
- The R&D meeting should be aligned with the recommendations of the Faculty Career Development Committee (CDC).
- Supervisors are asked to discuss the well-being of staff explicitly during R&D meetings. During the COVID pandemic, staff welfare was the most important point of discussion during preview and review meetings (parts of the R&D cycle) and R&D meetings themselves.

The above underlines the importance of the yearly Results and Development cycle (R&D cycle). In the R&D meetings, the above topics are discussed at least once a year. The R&D cycle includes preview and review meetings for each department. In these meetings, the talent development of individual staff members in terms of research, education, valorisation, organisation, and leadership is discussed.

It is self-evident that the above policy requires supervisors and staff to have certain competencies. As the expansion of development programmes for academic staff (Assistant, Associate and Full Professors, Lecturers and Researchers) at TU Delft level unfortunately lagged behind and could not meet expectations of the number of places available, the Faculty collaborated with the Faculty of Applied Sciences to develop its own curriculum for Assistant and Associate Professors in 2019. This curriculum was in use until the start of the COVID pandemic. After the COVID pandemic, two new curricula were developed at TU Delft level: one for Assistant and Associate Professors and one for Full Professors, with the latter funded at TU Delft level. Unfortunately, the number of places for the latter curriculum is limited and exceeded by demand, in part owing to a backlog due to COVID and the growth in the number of Full Professors, which in turn is due to internal promotion to Full Professor having recently become possible.

5.4.2 Diversity and Inclusivity (SA3)

Although diversity and inclusivity are clearly intertwined, inclusivity will be mainly discussed in chapter 4 and diversity will be discussed here. The Faculty recognises diversity is multi-faceted and encompasses gender and other demographics such as age, religion, sexual diversity, nationality, culture, physical ability and disability, but also character, educational level, organisational culture, field of expertise, and focus on science, engineering or design. The Faculty's focus has been on gender, nationality, and field of expertise, where the first is the subject of proactive policy presented below and the first is actively monitored (see section 6). To ensure the above is reflected in its recruitment and selection processes, the Faculty has started to implement non-biased selection training for vacancy holders.

In the Faculty Strategy 2019-2024, the Faculty committed to increasing the number of female Assistant, Associate and Full Professors and Lecturers to be in line with the relative share of women within the PhD population. For positions funded by the Sectorplans (Technical Sciences 1 & 2), the Faculty chose a higher target of 50% female hires (the requirement from the Ministry of Education, Culture and Science (OCW) was 35%). To achieve this, shortlists were required to include a minimum of 50% talented female candidates, and any exception to this rule could only be obtained by justifying this exception to the Dean. In so doing, the Faculty has actively stimulated vacancy holders to scout for female talent and employ the services of a dedicated recruitment agency. For Sectorplan Technical Sciences 1, this approach was successful, and the 50% target was achieved (for the other two Sectorplans hiring is ongoing). If we also include hiring for other vacancies, it still proves to be difficult to achieve the desired 50% female influx, also depending on the specific discipline (see also section 6 below).

5.5 Evidence

This section describes the indicators used in the next sections to assess the extent to which the Faculty's strategic aims (SA1-SA3) have been achieved. In so doing, we note the importance of considering staff privacy (GDPR) and acknowledge the practical limitations of extracting information from the Faculty's HR systems.

SA1 *Improve recognition and rewards for groups and individuals.*
Evidence: Employee satisfaction survey, participation of early-career staff in Departmental MTs, collaboration with early-career staff during policy design (e.g. new tenure track).

SA2 *Provide an* environment *for individuals to grow.*
Evidence: Career progression data (staff performance evaluations, recommendations by the Career Development Committee, average duration of promotion) and training and development programmes.

SA3 *Improve diversity and inclusivity.*
Evidence: Diversity statistics for new hires, growth in the amount of female faculty, female share per staff category, nationality per staff category.

5.6 Accomplishments during the past six years – research quality and societal relevance

This section describes and discusses the results achieved during the assessment period (2017-2022).

SA1 Improve recognition and rewards for groups and individuals.
The Faculty received what it considers to be a good score of 7.8 (on a scale of 1-10) in its employee satisfaction survey (Employee Monitor 2020 by IVA Onderwijs), which remained stable compared to the previous survey (2017) and is equal to the TU Delft average of 7.8 ('Working at TU Delft'). Early-career staff are increasingly involved in Departmental MTs, which were traditionally made up of only Full Professors, in different ways across different departments (see Table 34 in Appendix C.1). The Faculty takes pride in the way it has led changes to the tenure-track process at TU Delft level and the involvement of early-career staff in making these changes (see section 5.3) as a case study of how it would like to improve its recognition and rewards policies.

SA2 Provide an environment for individuals to grow.
Career progression data – Career development of academic staff is consistently monitored within the Faculty by the Faculty Career Development Committee (CDC), which is involved in four crucial stages in assessing the potential of individual employees (from selection and a mid-term evaluation to promotion to Associate Professor) as part of the 2012-2023 tenure-track policy. In a setting where the peer-review principle is used, candidates are assessed in a transparent manner based on the criteria established by the Faculty.

Table 12 summarises the recommendations of the CDC for the three evaluation stages: mid-term (after 2.5 years) and end-term (after five years) evaluations and promotion to Associate Professor. It is clear from this table that almost all staff members (95%) received positive recommendations for their mid-term evaluation (two staff members decided at this stage that an academic career was not a good fit); only 14% received a negative recommendation for their end-term evaluation, reducing to 8% after an additional year was given; and 80% (91% on second attempt) were promoted to Associate Professors. Of all staff appointed to the tenure track, only 13% left the track. Only two employees left the TU Delft. Taken together, the above numbers lead to the conclusion that the Faculty can attract and retain highly talented early-career Assistant (and Associate) Professors. Over the past years, the Faculty's policies have demonstrably resulted in an influx of high-quality staff (as determined by the Faculty CDC) with often rapid career development and an average tenure-track duration of seven years (from appointment as Assistant Professor and promotion to Associate Professor).

Table 12 Faculty Career Development Committee (CDC) recommendations during 2012-2022.

	Mid-term	End-term (after extra year)	Promotion to Associate Professor (second attempt)
Total	40	36	35
Positive	38	31 (33)	28 (32)
Negative	2	5 (3)	7 (2)

Training and development programmes – Different training and development programmes are available for Assistant and Associate Professors on the one hand and Full Professors on the other hand. In the years from its start in 1985 to 2022, 23 of the 56 Full Professors presently employed in the Faculty have participated in the TU Delft-level course *'Supervising in an Academic Context'.* This score of 41% is disappointing, especially considering the urgent need for leadership that goes beyond scientific leadership alone. One of the main reasons for this low rate is that this course is organised only once a year and just two participants per Faculty can participate. The Faculty has been searching for alternatives and found a suitable training centre in the UK. Although the COVID pandemic made this more difficult, six Full Professors have successfully participated in this course and rated their experience as positive.

The '*Development for Assistant and Associate Professors'* course was only organised in 2018 by the Faculty, and 18 Assistant and Associate Professors participated. The course was terminated at TU Delft level in 2019. The start of the design of a new course by the Faculty was impeded by the COVID pandemic. In 2022, a new course started at TU Delft level, and four Assistant and Associate Professors from the Faculty were able to participate. In addition, supervisors and HR advisors have been encouraging Assistant and Associate Professors to take part in externally provided leadership programmes. Although exact numbers are not kept, it is estimated that only nine Assistant and Associate Professors from a target group of 84 have made use of this opportunity.

SA3 Improve diversity and inclusivity.
Between 2017 and 2022, a steady increase in the representation of female academic staff can be observed in the Faculty, rising from 19% to 25%. The average percentage of women is presented in Table 13 below (see also Figure 44 in Appendix C.2 for a more detailed breakdown).

Table 13 Average share of female PhD candidates and academic staff.

	2017	2018	2019	2020	2021	2022
Share of female PhD candidates	29%	32%	33%	34%	36%	38%
Share of female academic staff	19%	19%	20%	23%	24%	25%

During the assessment period, six Associate Professors have been promoted to Full Professor (three male, three female). Moreover, we appointed the first female Department head during the review period. However, the share of women in the higher ranks still lags behind considerably (see Figure 44 in Appendix C.2), in large part because it takes time for early-career recruits to develop to Associate and Full Professors. Table 14 illustrates the gender break-down of tenure-track academic staff recruited during the assessment period. The average percentage of female tenure-track recruits (38%) is identical to the percentage of female PhD candidates, although we aim for a 50% target (see Table 14).

Table 14 Annual breakdown of the gender break-down (M/F) of newly recruited tenure-track academic staff.

	M	F	Total	F %
2017	1	2	3	67%
2018	6	2	8	25%
2019	4	3	7	43%
2020	9	5	14	36%
2021	9	5	14	36%
2022	4	3	7	43%
Total	**33**	**20**	**53**	**38%**

For reasons of employee privacy (GDPR), nationality is only known at the level of the three categories: National, European and non-European (EER vs Non-EER). In the category of Assistant Professors, the decline of National staff demonstrates a clear trend. This development is shown in Figure 45 in Appendix C.2. The Faculty values the benefits of a diverse academic community and welcomes this influx of international staff. Unavoidably, such increasing diversity in cultures and nationalities also leads to an increased variety of expectations, values and beliefs, sometimes resulting in disappointment, conflicts or undesirable behaviour. The Covid measures, which virtually ended all face-to-face contact, undoubtedly exacerbated some of these problems. As one of the measures to develop and reap the benefits of a diverse community and overcome negative side effects, the Faculty appointed a Faculty D&I officer in 2021, who will work closely with the TU Delft Diversity Officer (see chapter 4).

5.7 Strategy for the next six years

In conclusion, the Faculty looks back positively on the previous assessment period, both in terms of talent development and diversity, as it has been able to attract and retain talented staff from all over the world, and the new staff reflect a promising gender balance. The gender balance among senior ranks remains a prime cause for concern. Looking to the future, the Faculty has identified four strategic priorities.

5.7.1 Transition from tenure-track system to the Academic Career track

The previous tenure-track policy (2012-2023) was very demanding for tenure-track staff. The Faculty is therefore very pleased with the new Academic Career Track (ACT) that started in May 2023. In this policy, the focus is much more on development as the employee is given permanent employment after 18 months. These 18 months should be seen as a period in which both parties (employer and employee) can ascertain whether the choice for this job, is the right one. A very positive aspect is that the entire track is now supported by training and courses. The Faculty should continue actively using recommendations by the Faculty Career Development Committee in the R&D meetings and ensure that staff actually make use of the many options available to develop, including courses.

5.7.2 Diversity and inclusion

The ‘Recognition and Rewards’ policy will contribute to meeting the goals of staff development in a broad sense. This will also contribute to a diversity that goes beyond nationality and gender. To select a diverse pool of staff, non-bias selection procedures and training will be further developed and implemented across the Faculty to ensure that selection and appraisal procedures are increasingly more inclusive. Moreover, apart from increasing the diversity of our newly hired staff we will pay attention to an increased diversity in progression to higher ranks. An important step to achieve this will be to maintain a systematic overview (at MT level with HR support) of opportunities for promotion to leadership positions (e.g. Section Heads, major committees, etc.). Other measures include more open application procedures and the recently adopted organisational principle that Section Head positions are only for a finite period. Measures will also be taken to prevent undesirable behaviour and ensure its early detection, and entry points for reporting will be made more easily accessible.

5.7.3 Workload

Staff workload is an important concern. Increasing the number of staff through the Sector-plan positions should alleviate this but there is a risk that some workload issues will remain ‘self-inflicted’ (by individual staff, supervisors, or the Faculty’s academic culture). Addressing this requires both training and coaching but also for supervisors to start looking at the functioning of the organisation as a whole and not, as is often the case now, only at the level of the individual employee.

The Management Team of the Faculty and the Departments must start analysing the total workload across the different components (science, education, valorisation and organisation) of their staff members and make responsible choices. This analysis and these choices need to be made in a context where more and more external demands are placed on the Faculty and the University that require adhering to legal, financial, integrity and health-and-safety requirements and regulations. Analysis of workload also requires the completion and implementation of the teaching workload model ('Model of Educational tasks'), which specifies which task is done by whom and how many hours this task represents.

5.7.4 Development for early-career and existing staff and supervisors

Implementation of the ACT and the Recognition and Rewards policy requires leadership skills from (senior) supervisors, who have often not received training for this, but also from early-career Assistant Professors in the Academic Career Track. It requires the ability to value one's own development and that of one's colleagues, for which the ability to self-reflect is invaluable. Ambitious early-career staff who have been selected based on their ambition and not always on this ability must be coached in this process. The Faculty will need to pay more attention to the development of leadership skills of Associate and Full Professors.

Table 15 SWOT analysis Human Resources Policy.

	Strengths	Weaknesses
Internal view	• Positive and open atmosphere in the Faculty, encouraging discussions on challenging topics. • Involvement of early-career employees in shaping strategy and implementing new policies. • Faculty's ability to attract and retain talent (in terms of the CDC). • R&D and recommendations of the Faculty Career Development Committee (CDC) are already highly integrated.	• Lack of diversity in higher ranks, particularly in terms of gender and ethnicity. • Heavy workload for staff members, potentially impacting work-life balance, and well-being. • Difficulty in balancing research and teaching responsibilities. • Insufficient training opportunities in leadership skills at university level.
	Opportunities	**Threats**
External view	• Increasing awareness about the importance of unbiased recruitment and selection processes. • Further increasing the active scouting of (female) talent. • Transitioning from an R&D system with a focus on results to a system that emphasises development and the future.	• Competition from other universities and industries for top talent, making recruitment and retention challenging.

6. Department of Engineering Structures

6.1 Introduction

The department of Engineering Structures (ES) was formed in 2018 to develop resilient, smart and sustainable (infra)structures that meet societal demands in transportation, energy transition and sustainable reuse. The research agenda of ES is mainly composed of two parts: (i) the modelling and (ii) the experimental characterisation of mechanical behaviour of materials and structural components. The experimental part of the research is performed in the Macromechanical Laboratory (MacroLab). The ES department is responsible for replace with the MacroLab, which carries out small and full-scale testing, allowing the development and validation of physics-based and data-driven structural models.

The ES department formally consists of sections, see Table 16, and the MacroLab. The actual staff composition can be found in Appendix B.1. Besides the formal division in sections, the research unit relates its scientific and social identity to four themes. These themes encapsulate both the pursuit of scientific innovation and the need to meet the current and future societal needs, concerning sustainability and the integrity of existing and new structures. The four themes are as follows.

A. Structures for energy transition (Struct. En. Trans.):
One of the challenges in structural engineering concerns the development of new support structures for renewable energy technologies. This theme is expected to put forward engineering contributions of the ES department in terms of innovative design, transportation, installation, and monitoring solutions, facilitating the technological and societal challenges to shift towards competitive renewable energy.

B. Recycling and circular structural systems (Rec. Circ. Struct. Sys.):
Recycling and circular systems in the construction sector play a crucial role in achieving societal goals, such as reducing the negative environmental impact of resource consumption, mitigating waste generation in engineering structures, and working towards a sustainable future. Through its high-level research, the ES department aims to influence construction and other Civil Engineering related industries to adopt new techniques for more environmentally friendly growth.

C. Transport infrastructures for future-proof built environment (Transp. Infr.):
Transport infrastructures are among the key factors in a connected society to enhance the quality of life. It provides necessary conditions to build a future-proof environment that facilitates connectivity and accessibility in a sustainable manner, and functions as a solid cornerstone for smart cities.

D. Structural integrity through innovative monitoring, damage assessment, prediction and maintenance (Struct. Integr.):
One of the most pressing challenges in Europe concerns the structural assessment of existing and outdated constructions, and the development of new measurement tools for future structures that must meet stringent sustainability criteria. Research needs in these areas have emerged, requiring innovative approaches to achieve smart and uniquely enhanced solutions to safeguard structures.

To illustrate the link between the sections within the ES department and the themes, Table 16 highlights the contribution of each section to each theme. Note that the MacroLab serves as common ground for all the related experimental research activities. It is also worth highlighting that the theme related to structural integrity receives the largest attention by all the research groups.

Table 16 Qualitative overview of the contribution of the different sections to each theme. The number of check marks corresponds to the level of contribution of each section to each theme, with more check marks corresponding to a greater contribution (scale 0-3).

		Themes			
		Struct. En. Trans.	Rec. Circ. Struct. Sys.	Transp. Infr.	Struct. Integr.
Sections	Bio-based Structures & Materials (BSM)		✓✓		✓✓✓
	Concrete Structures (CS)		✓	✓✓	✓✓✓
	Dynamics of Solids and Structures (DSS)	✓✓✓		✓✓	✓✓
	Mechanics and Physics of Structures (MPS)	✓✓		✓✓	✓✓✓
	Pavement Engineering (PE)	✓	✓✓	✓✓✓	✓✓
	Railway Engineering (RE)	✓	✓	✓✓✓	✓✓
	Resources & Recycling (RR)		✓✓✓		✓✓
	Steel & Composite Structures (SCS)	✓✓✓	✓	✓	✓✓

The current report was written by two Assistant Professors, and reviewed and edited by the Department Head, two Full Professors and the Executive Secretary (all together the 'writing team'). The main inputs were collected through specific requests sent by email or online surveys. At the same time, several periodic meetings with the heads of the sections were organised to showcase the progress of the report and collect further input. Different group meetings were organised with the Management Team (MT-ES) and the Young Management Team (YMT) (see section 6.4), as well as a few individual meetings with the chair of the PhD council and other selected colleagues of the ES department. The writing team together with the head of the MacroLab visited the University of Illinois, Urbana-Champaign (UIUC) for comparative assessment as described in section 6.7.

6.2 Mission and strategic aims of the past six years

The mission of the ES department is to provide world-class scientific innovation to assess the integrity of the built environment, to support mitigation strategies for climate change, and to tackle urbanisation challenges due to a growing world population. The research mission is inherently linked to educating the new generation of engineers and scientists. Importantly, the mission is in line with TU Delft's vision and emerging strategies for the future, explained in detail in the TU Delft Strategic Priorities 2022-2024 report.

The mission is pursued in the framework defined by the aforementioned themes. Each theme is strongly linked to traditional disciplines of mechanics of materials, solids and structures, and transport systems science. Moreover, the link also extends to current societal needs at a national and international level, encompassing urbanisation challenges and the transition to renewable energy systems. The relevance of focussing on *structures for the energy transition* has been specifically put on the spot by the ambitious task of the Dutch government to reach 20 GW production from wind energy by 2030 and 70 GW by 2050[30]. To achieve this target, innovative offshore structures are needed, not to mention new future-proof solutions for the production, transportation, installation, monitoring, decommissioning and re-use of such structures.

Similarly, the importance of *recycling and circular structural system* as a theme was emphasised since by 2050[31] the carbon neutral status and the design of circular constructions are non-negotiable constraints anymore. The ES department's research helps industry to move from a waste-driven perspective aiming at processing waste for a gate fee, to a demand-driven perspective, where economic drivers come from producing materials that are needed for construction and manufacturing and can replace virgin materials. In terms of science, this means digitalisation, artificial intelligence (AI) and sensor-based sorting, processing and certification.

Lastly, both themes *transport infrastructure* and *structural integrity* are strongly linked to tackle the current urbanisation challenge due to a growing population combined with an aged and outdated civil infrastructure landscape, where functionality, reliability and integrity are under constant scrutiny. Specifically, the majority of large fixed and movable bridges, river gates and quay walls in the Netherlands require more accurate assessment methods and effective in-situ monitoring strategies for accurate predictions of the technical lifetime of the transport infrastructure.

In order to effectively accomplish the mission, specific aims and strategies related to the ES department have been established and implemented. In addition to the Faculty-related strategic aims, the ES department further defined six overarching strategic aims. The first aim (1) was to support and consolidate the four aforementioned themes in order to strengthen the department's leading position, at a national and at an international level. The second overarching aim (2) was to translate research results into effective technologies, thereby facilitating the development and consequent transfer of knowledge to the industry. The third overarching aim (3) was to work across different TRLs (Technology Readiness Levels), to cover curiosity- and application-driven research. The fourth aim (4) was to strengthen inter- and intra-departmental collaboration to jointly progress in the idenfitied themes. This allows to tackle the scientific challenges from a multidisciplinary perspective. The fifth strategic aim (5) aligns with one of the Faculty aims, envisioning the growth of an inclusive academic culture. The last strategic aim (6) was meant to reach a healthy financial balance between the different money-streams to support aim (3).

[30] https://english.rvo.nl/information/offshore-wind-energy/offshore-wind-energy-plans-2030-2050: accessed on 23/06/2023.

[31] https://www.government.nl/latest/news/2021/03/24/the-circular-economy-is-crucial-to-achieving-the-paris-climate-goals: accessed on 23/06/2023.

6.3 Follow-up from previous assessments

Constructive recommendations and feedback were raised during the last end- and mid-term assessment reports, aimed at suggesting strategies to further improve the quality of the ES department. This section summarises the most relevant recommendations and provides a first glimpse of the corresponding chosen strategies. Note that a more exhaustive description of the strategies is provided in section 6.4.

Recommendation 1: Need for action to support the research groups of the ES department

Three new Assistant Professors and one Associate Professor were hired over the past three years within the Sectorplan to cover areas such as construction material degradation, interface mechanics, circularity-based design and structural health monitoring. Besides the Sectorplan hirings, another new Assistant Professor was hired under the TU Delft AI Initiative, to cover the research area at the interface between engineering structures and AI. To support the research groups, large investments were devoted to the re-organisation of the MacroLab, starting by the establishment of a new Head of the MacroLab and by new hirings of technicians in the MacroLab. These hirings and lab investments were meant to fairly support each group in the department. In fact, all groups were invited to submit their application/proposal to the MT-ES before the final hiring/purchase process started. All the implemented strategies are meant to achieve the overarching aims (1), (3), (4) and (5).

Recommendation 2:

a. Preserve and strengthen the balance between scientific and societal needs

b. Endeavouring to meet societal needs in the domain of Civil Engineering may systematically lead to a negative impact on the H-indices of the academic staff, which may hinder the acquisition of external funding

To strengthen the above-mentioned balance, in 2020, the ES department decided to introduce a new section, namely “Mechanics and Physics of Structures (MPS)”, with the aim to transcend the traditional section boundaries defined by specific Civil Engineering applications, and to seek a stronger link between the curiosity- and application-driven research directions. Two of the academic staff members of the MPS section were hired within the Sectorplan, focussing on topics such as interface mechanics and structural health monitoring, that have been identified as crucial at a department level. In addition to the creation of the MPS section, one of the imposed requirements in the hiring process of the new Head of the MacroLab was to have a scientific PhD background. The requirement mandated was to facilitate the implementation of research ideas into laboratory activities. Concerning the acquisition of external funding, in the last six years, the ES department was rather successful (see Appendix B.2), ensuring continuity and evolution of the research directions, and a good balance between national funding (mainly industry-related), European-level funding and individual NWO research grants. These adopted strategies were meant to achieve the overarching aims (2), (3) and (6).

Recommendation 3: Clearly formulate the research direction in terms of safety and security of structures

In the last three years, the ES department significantly invested in new experimental equipment, focussing the attention on the multi-physics aspect of the different challenges in Civil Engineering and on non-contact structural health monitoring, which encompasses the whole investigation process from monitoring the structural response to the assessment of the structural integrity. The corresponding implemented strategies are directly linked to the achievement of the overarching aims (3) and (4).

Recommendation 4: A weak cohesion of the department within the Faculty research theme. Extend the network to enlarge its impact.
Since its creation in 2018, besides the existing collaboration with the Offshore section in the HE department, the ES department made significant efforts to enlarge its network at a Faculty level through joint research activities. The Railway Engineering section and the scientific members of the Transport & Planning (T&P) department formed a research-based alliance with Prorail, which also led to a new TU Delft-wide Railway Institute, founded in 2021. The institute is led by the representatives of the ES department and functions in close cooperation with members from different faculties and departments, including further departments of the Faculty, namely T&P, 3MD and Geoscience & Engineering (GSE).

It is worth mentioning that through the granted project UnRavel, a collaboration was established between the ES and the T&P department. The project aims at providing a better understanding of topics related to pavement ravelling predictions and its traffic-related causes for porous asphalt. Moreover, in 2022, a member of the MPS section partnered up with scientific members of the GSE, Geoscience & Remote Sensing (GRS) and HE departments to secure the NWO-NWA LiveQuay grant (National Science Agenda) aimed at investigating bridges and quay walls in Amsterdam, The Hague and Rotterdam. Besides the granted projects, most of the scientific members in the ES department are part of joint supervision teams for MSc thesis projects across departments, with the aim to identify common grounds for future research proposal submissions. The strategies to extend the network are all meant to achieve the overarching aims (1), (3), (4), and (6).

Recommendation 5: A critical point of attention by the assessment committee was the gender balance within the department.
Aims related to diversity and inclusiveness were established at a Faculty level and embraced by the ES department. It is worth mentioning, that the hirings over the last six years in the ES department reflect a more balanced ratio of 50/50. Specifically, the new hirings for UD, UHD, HL level since 2020 are: six female and five male staff members.

6.4 Strategic process of the past six years

Besides the strategies as a result of past recommendations, this section provides a complete picture of the implemented strategies on departmental level to achieve overarching department and Faculty aims. The description of the strategies is clustered per specific aim.

Overarching aim (1): strengthen the leading position within the four themes
The ES department encourages and seeks the participation in topics that cover cutting-edge technology in different sectors, spanning among the four identified themes. The relevance on identifying cutting-edge topics relevant for ES, is also reflected in the diversified hiring strategy adopted by the department for the Sectorplan and other positions. Specifically, to enhance the outreach and the quality of the current research, common topics/areas of interest are identified that complement existing research groups within the ES department. To strengthen the international leading position, in the last six years, the ES department decided to be active in contributing to scientific committees and organizing international conferences.

Overarching aim (2): translate research results into effective technologies
The ES department focuses on more application-driven research projects, without weakening the connection to curiosity-driven research (as demonstrated by the establishment of aim (3) and its corresponding strategies). Within this context, the strategy is to establish long-term collaborations with industrial partners, whenever possible, to translate research results into techniques and methodologies.

Patenting and creation of spin-off companies are among the strategies used to effectively translate research into effective technologies. The view of the ES department on such regard is to first secure the ownership rights to an invention or proposed innovative technique, and at the same time encourage public disclosure of the proposed technical and inventive knowledge.

Overarching aim (3): include research activities across different TRLs
To find an optimal balance between fundamental research activities and translating research results into effective technology, a large investment (1.5m€) was placed to increase the testing facility of the MacroLab. Two new sub-laboratories were created: the Multiphysics laboratory and the non-contact Structural Health Monitoring laboratory. While the former laboratory stemmed from the need to tackle fundamental research questions related to Civil Engineering (e.g. understanding noise propagation and non-conservative forces), the latter laboratory is meant to cope with more application-driven problems related to the monitoring and assessment of the structural behaviour and its integrity. Besides the testing facilities, the ES department decided to review and re-structure the organisation of the MacroLab, by hiring a new Head of the MacroLab.

Overarching aim (4): align the different sections to the four identified Themes
The ES department encourages joint intra-departmental supervision teams for PhD candidates and postdocs to enhance the chance in tackling the research challenge from a multidisciplinary perspective.

Overarching aim (5): growth of an inclusive academic culture
The ES department aims to instil a sense of belonging to the department to all staff members (academics, technicians and administrative staff). In this regard, the ES department implemented the following strategies:

- Quarterly meetings between the Department Head, Executive Secretary, the HR advisor and Academic Career Trackers were held;
- The Young MT (YMT) was installed (see section 6.6);
- Strategy Days (SDs) were organised.

The ES department also put a strong emphasis on improving the communication skills among the staff members, considering the multi-cultural nature of the department, by organizing empathic communication trainings.

Overarching aim (6): reach a healthy financial status
The ES department aims at diversifying the nature of funding and prioritizing long-term funding opportunities. Considering the TU Delft's financial constraint, priority is given to 2nd and 3rd stream money (national, European and industry-related project, respectively).

Faculty aims: PhD training, Academic Culture, Open Science and HR policy
PhD Training: In line with the guidelines and framework provided by the University Graduate School, the ES department aims at improving the PhD academic path, especially in terms of reducing the duration of PhD candidates and to empower their position and role within the department. In 2021, the ES department established a departmental PhD council composed of representative PhD candidates from each section. The goal of the PhD council is to stimulate the participation of PhD candidates in the department and the faculty and involve them in the decision-making process. The PhD council also plays a role in collecting and channelling data about the status and well-being of the PhD candidates in the department, with the aim to identify all possible sources that may hinder a successful PhD path. Moreover, selected representatives of the ES PhD council take part in the Faculty PhD council and in the YMT (see section 6.6). Furthermore, the ES PhD council takes an active role in organising group-building events, beneficial for the whole department.

Open Science: Adhering to the principles of Open Science constitutes a strategy to achieve the overarching aim (2). The ES department made significant progress in terms of open access journal papers, increasing the ratio between open and closed contribution from 50% (in 2017) to 90% (in 2022). Besides the number of open access contributions, the ES department aims at establishing the Open Science “mindset” as a common habit to ensure accessibility of the developed knowledge. Among the multiple routes to achieve such an aim, one is the exchange of ideas and research contributions within the department itself. Once a month, the ES department organises departmental colloquia during which the progress of ongoing research and the use of laboratory equipment are discussed. The overall organisation and structure of the ES colloquia are periodically overseen by an early-career academic member (Academic Career Tracker or Assistant Professor) and a PhD candidate. Each monthly colloquium is chaired by a PhD candidate, and constitutes an initial round of updates concerning the department and Faculty decisions, a short round of introduction of the newly hired staff members within the department, and two presentations that may span from research-related topics to organisation-related matters (e.g. data-management, graduate school, funding etc). Besides the ES colloquia, several seminars at a section level are periodically organised with the aim of sharing ideas. In terms of open access for data sets, a total of five data sets were made available during the last six years, compared to a total number of 188 of the whole Faculty.

HR policy: In the ES department, each candidate set for promotion has to give a presentation during the MT-ES meeting. The MT-ES provides constructive feedback in order to set up a path for a successful promotion. If needed, members of the MT-ES provide help in improving the presentation quality as well. Besides the assessment on research quality and teaching duties, a significant weight is put on organisational skills and the attitude of being a team player before recommending someone for promotion, embracing the principles of the position paper “Room for everyone’s talent”. In this framework, plans are formulated and discussed in each R&D cycle, related to the main direction of research, teaching, organisation and leadership of each member of the department. In the last six years, the ES department promoted a total of five members from UD to UHD, specifically, one in 2019, three in 2021 and one in 2022.

The ES department also introduced recent changes concerning the hiring procedure for PhD candidates and postdocs. The Executive Secretary serves as the first contact point whenever a position needs to be opened and advertised and is also involved in all the interviews of the shortlisted candidates, in order to ensure the department’s values and expectations are equally met for each recruitment made. Subsequently, all the needed forms for opening a position are then checked by the 3-pairs-of-eye principle, specifically by the executive secretary, HR and the Department Head.

6.5 Evidence

This section describes the selected indicators able to picture the research quality of the ES department, with reference to the defined overarching aims discussed in section 6.2. Table 17, provides a summary of such indicators, grouped per scientific quality, societal relevance and indicators that embrace both aspects. For each category, indicators are classified in terms of metrics representative of a delivered output, and indicators that highlight the use and recognition of the delivered output.

Table 17 Chosen indicators to quantify the scientific and societal accomplishments. The corresponding quantity is reported in bold within brackets.

	Scientific quality	Both	Societal relevance
Outputs	• Number of scientific contribution **(913)**	• Demonstrators **(9)** • Patents **(20)**	• Media **(29)** • Masterclass/MOOC **(4)**
Use	• Citation counts **(7998)** • Projects with academic colleagues (inside/ outside) **(32)**	• Methods developed for design practice **(9)** • Project with industrial partners **(65)**	• Projects with societal parties **(11)** • Spin-off **(3)**
Recognition	• Grants awarded **(30)** • Presence in Editorial Boards **(29)** • Presence in scientific committees **(86)**	• Invited talks in University and for industry **(145)**	• Soc./tech. committees for standardisation (Eurocode etc.) **(16)**

In terms of scientific quality, the number of scientific contributions, inclusive of peer-reviewed journal and conference papers, remain important means to trigger scientific discussion in the various fields of interest and to measure part of the achievements of aim (1). The ES department values publications in internationally recognised journals in the field of mechanics and structures of solids, transport science, data science and sustainability and recycling sector. The use of the published output can be quantitively assessed by the citation count, and qualitatively by the presence of the ES scientific members in research projects carried out in collaboration with colleagues from the same Faculty or from international universities. The latter is a direct consequence of the recognised relevance of the published output and its use in multidisciplinary projects. Both indicators allow to assess part of the achievements linked to all the aims mentioned in section 6.2. The degree of recognition is also assessed by the number of grants awarded, that reflects the leading position of the ES scientific members in their respective theme (aim 1), fosters academic growth (aim 5) and ensures a healthy financial status (aims 6). Moreover, the presence of ES scientific members in the editorial boards of well-recognised journals in the respective field of interest, the presence in scientific committees, and the active involvement in the organisation of international conferences over the past six years do contribute as well in assessing achievement of aims (1) and (5).

In terms of societal relevance, the presence in the media was considered of utmost importance concerning the trending channelling of information. In a similar manner, Masterclasses and MOOCs for professionals also became a new format of transferring knowledge to industry and society. Both indicators allow to assess part of the achievements of aims (1) and (2). For the Civil Engineering community and also for society itself, the development and update of engineering standards for design practice is a fundamental aspect, in which several ES members were actively involved to achieve aims (1) to (3). Further strategies to valorise the transfer of research into effective technology (see aim 3), consists of the creation of Spin-Offs and the participation in projects with societal parties.

Additional indicators were defined, to assess outputs that are characterised by a combined scientific and societal relevance. For instance, lessons and insights are often taken from demonstrators, that eventually also led to publications, directed to achieve aims (1) and (3). Developed methods for design practice and direct collaboration with industrial partners, foster the research transfer into an effective use. Finally, the visibility and recognition of the ES scientific members can be directly reflected by the number of invited talks provided over the last six years, in terms of delivered Keynote Lectures, invited talks delivered at international Universities or talks provided in workshops with Industrial or Societal parties (linked to aims 1 and 5).

Besides the indicators, two case studies (see Appendix A.1) were selected as evidence to demonstrate the commitment of the ES department towards highly scientifically relevant and societal impactful activities. Both case studies stand out due to their significant contribution in helping the ES department to achieve all the aims from 1 to 6, spanning from the strengthening of the leading position in the field, transforming research results into effective technology, especially by ranging through different TRLs within the projects and helping the ES department in achieving a healthy financial status. Both these case studies contributed significantly towards the indicators mentioned in the Table 17, see section 6.6 and the case studies in Appendix A.1.1 and A.1.2 for more details. The first case study is the C2CA (Concrete to Cement & Aggregates) project, which aimed to create sustainable high-grade circular concrete. The project aimed to work on the dismantling process, enabling a deeper circularity at a reduced cost (Figure 15a). The second case study is the GDP (Gentle Driving of Piles) project, in which the goal was to invent a new piling method, by means of a combined axial and high-frequency torsional vibration load, which reduces the emitted sound level and enables superior drivability (Figure 15b). The latter case study is of high relevance considering the significant investment carried out by the Dutch Government in Wind Energy, which constitutes one of the largest economical assets of the Netherlands.

Figure 15 a) view of the C2CA equipment in operation; b) image of the developed GDP shaker.

6.6 Accomplishments during the past six years – research quality and societal relevance

This section highlights the scientific achievements and the corresponding societal impact obtained during the last six years. With reference to the themes, the overarching aims and the two selected case studies corresponding accomplishments are described. Moreover, the main outcomes are described, especially with reference to the indicators.

6.6.1 Achievements through the case studies

Case study 1: Resource & Recycling - C2CA (see Appendix A.1.1)
The technologies developed in C2CA led to prototypes, and a spin-off C2CA Technology, which received the EU Innovation Radar prize for the most sustainable technology in 2021. In terms of important scientific achievements, it is worth mentioning the results for the energy-efficient large-scale liberation of binders and aggregates from EoL (End of Life) concrete. Moreover, an online sensor-based measurement was developed to monitor all the relevant quality factors of recycled aggregates, in order to increase transparency and trust in the construction materials value chain. This project also resulted in follow-up projects, such as the ICEBERG and DETOCS project, which led to the hiring of a new Assistant Professor.

Case study 2: Dynamics of Solids and Structures - GDP (see Appendix A.1.2)
The GDP technology has been successfully patented by TU Delft, generating research lines on which three PhD candidates and seven postdocs kept working over the last six years. In terms of funding, the money stream is linked to RVO (Rijksdienst for Ondernemend Nederland) and the application was submitted with the international GROW consortium[32]. Besides a patent, a spin-off company has been established to manufacture and market the developed GDP shakers used for the new piling method. To achieve these results, scientific challenges had to be tackled through innovative solutions which were presented at several keynote lectures and regular presentations delivered at international conferences, such as EURODYN 2020 (Greece), ENOC 2022 (France) and ICoEV2020 (Portugal). One of the journal publications based on research on the GDP technology received the David Hislop award for the best paper in offshore geo-engineering by the Institute of Civil Engineers of the UK.

6.6.2 Achievements per overarching aim

Overarching aim (1): Strengthen the leading position within the four Themes
The ES department initiated several projects (see section 6.6.3) in topics that cover cutting-edge technology in different sectors, spanning among the four identified themes. The diversified hiring strategy adopted by the department for the Sectorplan and other positions helped to enhance the outreach and the quality of the current research. Identified common topics/areas of interest that complement existing research groups within the ES department let to the hiring of four Sectorplan-positions: construction material degradation, interface mechanics, circularity-based design and structural health monitoring. A new staff member is given the freedom to choose and join a section that best represents their research portfolio.

Overarching aim (2): translate research results into effective technologies
The ES department selected more application-driven research projects (see case studies in Appendix A.1). It is worth highlighting that the department favoured projects that had a strong connection between scientific investigation and application, which does provide further challenges for PhD candidates and the supervision teams to ensure the necessary scientific contribution. This challenge became more pressing for projects related to long-term funding with large societal/industrial relevance. The ES department recognised these challenges, which led to an increased level of awareness of the PhD

[32] https://grow-offshorewind.nl.

candidate's supervision team towards ensuring a scientific-centred PhD thesis. The ES department encouraged public disclosure of the proposed technical and inventive knowledge, during patenting and the creation of spin-off companies. With reference to open science, patent databases can be viewed as the oldest form of open-source repositories. Examples of patents are described in the Achievements per Themes sub-section (see section 6.6.3).

Overarching aim (3): include research activities across different TRLs
The investment (1.5m€) was realised and the Multiphysics laboratory and the non-contact Structural Health Monitoring laboratory are in operation. The organisation of the MacroLab has been restructured and a new Head of the MacroLab is hired. Further accomplishments are described in section 6.3.

Overarching aim (4): align the different sections to the four identified Themes
This has been realised between some sections, for example, a PhD candidate jointly supervised by the MPS and Bio-based Structures & Materials sections, focusing on the tribological behaviour of wood surfaces, and a postdoc who is jointly supervised between Pavement Engineering (PE), Concrete Structures (CS) and Railway Engineering (RE) for the project INFRACOMS, CEDR, 2021. In this project, all three sections are jointly participating and bringing their own expertise to solve problems related to remote condition monitoring of physical road assets. Moreover, the YMT (see paragraph below) was created to encourage cooperation between the research groups of the department and a continuous flow of information among the different sections.

Overarching aim (5): growth of an inclusive academic culture
With regards to growth of an inclusive academic culture aim, the following accomplishments were achieved:

- Quarterly meetings between the Department Head, Executive Secretary, the HR advisor and Academic Career Trackers to discuss general day-to-day issues and well-being. Furthermore, the ES department has made a strategy to increase the participation of early career academic staff members in the department-related decision-making processes as well. This can be seen by that fact that in the last six years, the MT-ES included on average three (out of ten members) early career academic members. These include section leaders and the chair of the YMT.
- The YMT, which is an innovative entity of the department within the Faculty created in 2018, provides a non-hierarchical platform for early-career academic staff members to work actively for the well-being of the academic staff and the future vision of the ES department. Meetings occur every four weeks, and the chair is elected every six months, with no exclusive rights. The task of the chair is to set up the agenda and take part in the MT-ES meetings. The aim of the YMT is to share and discuss information from the MT-ES and managing/leading delegated tasks, to brainstorm and develop initiatives to be proposed to the MT-ES, to influence the strategy of the department on short-, mid- and long-term, to provide hands-on experience of early-career academic staff in management and strategy process, to facilitate the communication of issues and ideas from the PhD Council to the MT-ES, to organise the Strategy Days (SDs, see next paragraph) and to create task-forces (e.g. lab environment organisation and assessment, stress level identification for staff members, office renovation). Concerning the composition, there is no limit to the number of scientific members that participate in the YMT, provided each section is represented. Moreover, one representative from the PhD Council is also a YMT member. However, other colleagues are also invited if specific issues or important items need to be discussed that concern them.

- SDs are thematic periodic meetings that usually occur every four months and which are open to all scientific staff members composed of Assistant, Associate, Full Professors, teaching and research staff, project managers, technicians and secretaries. Occasionally, postdocs and PhD candidates are also invited to join, depending on the theme of the SD. The topics of these meetings are aligned with the ES department's strategies and aims (see section 6.1). Moreover, the current and the near-future challenges of the department, and their proposed actions and strategies are discussed/ agreed. Examples of the topic are Finance, Open science, Intra-departmental cooperation, MacroLab organisation and Education.
- The ES PhD council had a rather positive impact since it became a first point of contact for the PhD candidates, especially for newly hired candidates. Moreover, the relevance of the council was apparent especially during COVID time, between 2020 and the 2022, during which the well-being of the PhD candidates was systematically monitored.
- The ES department participated in the Faculty empathic communication training.

Overarching aim (6): reach a healthy financial status

The ES department has developed during this period towards a positive balance and large raise on total income. This income stayed diverse with a considerable grow within 2nd and 3rd stream money (National, European and Industry-related project, respectively).

6.6.3 Achievements per themes

Theme A: Structures for the energy transition

The main activity of the ES department was focused on the technical bottlenecks of technologies such as connections for increasing sizes and facilitating speed for fabrication and installation of support structures, improving knowledge of environmental influence and durability of the structures. A series of successful projects related to the innovation in supporting structures for wind turbines are the four OFWEC (Offshore Wedge Connection) projects in which the Steel & Composite Structures (SCS) section was involved. The first project started in 2018, and OFWEC 4 is planned to finish in the summer of 2024. The projects have resulted in the development of a unique connection, the C1 Wedge Connection, which is now already operational in one of the largest wind turbines in the world and is considered a very promising solution for heavily loaded connections for future wind turbines beyond 15MW. With reference to the developed technology, the company C1 Connections was created based on successful MSc thesis projects, and our students have become the first employed staff in the company. The research also resulted in one PhD project. The projects were financed by RVO, Windenergie op zee program. It is self-explanatory that the above-mentioned example clearly covers all the overarching aims (1, 2, 4, 5 and 6), except (3). The SCS section is also involved in the organisation of the 10th Eurosteel Conference 2023. In this theme, the ES department is also involved in carrying out research at both the curiosity- and application-driven level. To showcase the involvement of the ES on curiosity-driven research an example can be taken from the hirings due to the Sectorplan investments. Through an initial collaboration between the scientific members of the MPS and Dynamics of Solids and Structures (DSS) sections, efforts were made in developing fundamental research concerning techniques for physics-enhanced Machine Learning (ML) strategies in order to improve monitoring strategies of critical structures for the energy transition. This has led to the development of a virtual sensing technique for wind turbine applications in collaboration with Siemens Gamesa. Moreover, this has enabled secure European funding to further develop and apply these techniques to critical structures and components for the energy transition including the performances of friction pads used to support monopiles during offshore transportation for the construction of offshore wind turbines. The mentioned examples contributed the ES department in achieving its overarching aims (1- 5). In terms of collaboration between the MPS and the DSS sections, it is worth mentioning their active involvement in the organisation of the 12th International Conference on Structural Dynamics (2023, Delft, NL).

Theme B: Recycling and circular structural systems

The ES department recognises the need to reduce the carbon footprint and mitigate natural resource depletion and therefore focuses on transition to a circular economy. Besides the described C2CA case-study, other examples include the REDUCE (Reuse and demountability using steel structures and the circular economy) and GENCOM (GENeric behaviour of COMposite structures by partial interaction of two materials) projects, aimed at studying the reuse and demountability of composite (steel-concrete) structures and the behaviour of partial interaction between two materials. The project provided methodologies, tools and guidance to assist in the design for deconstruction. It led to a new material (reinforced resin) used in shear connections for demountable structures when two materials are used in applications of circular buildings and bridges. The project has created a theoretical basis for implementing the new material in the construction sector. It has shown a way to combine fundamental and applied research, international and national financing schemes, education, and research, and as such covering the aims (2, 3, and 6).

Theme C: Transport infrastructure for future-proof built environment

Two sections that are heavily involved with this research theme are the PE and RE sections. Over the last six years, the RE section has developed a research-based alliance with Prorail, which is responsible for the maintenance and development of the Dutch railway tracks, and the PE section works on close cooperation with Rijkswaterstaat, the Dutch Ministry of Infrastructure and Water Management on various research topics. Concerning the RE section, the Maxlife project is worth mentioning. It is an ongoing project that aims to analyse the complete evolution process of rail rolling contact fatigue (a major problem in the railway industry) from micro- to macro-scope to obtain a full understanding of the crack initiation and growth mechanism as a function of rail material, loading condition and grinding parameters. The Maxlife project benefitted from the involvement of several industrial partners (ProRail, M2i, British Steel, French Steel, SKF). Among these industrial partners SKF is worth mentioning, since it is a leading bearing R&D & manufacturing company in the field of Mechanical Engineering, showcasing the potential of the research project to encompass a larger spectrum of applications. The Maxlife project originates from successful results of previous projects on a similar topic, that led to a guideline for best industry practice for UIC (the worldwide Railway organisation) and two patents. The knowledge developed in this study will contribute to an increase in the efficiency and cost-effectiveness of the maintenance and much safer operation of railways. The project connects well with the strategic aims of the ES department (1, 3, 4 and 6). In 2018, the RE section acted as the main organiser for the 11th International Conference on Contact Mechanics and Wear of Rail/Wheel System, held in Delft. Another successful project is the Epoxyasfalt project. The PE section carried out their research on durable and re-usable epoxy modified asphalt mixes for the Dutch paving industry in close cooperation with the provinces of Noord- Holland and Gelderland. The goal of this project was to optimise the balance between epoxies and asphalt binder technologies and gain a better understanding of the chemo-physico-mechanical processes involved in their interaction, to increase durability, environmental friendliness, and lifespan. The project resulted in the successful completion of a PhD and at the same time made it possible to hire two postdocs. 12 journal and 18 conference papers were published in relevant journals and conferences, and as such the project reflects on several aims (1, 2, 3, 5 and 6). Within the PE section, it is worth mentioning the acquisition of the NWO Veni Fellowship, by an early-career academic member, with the aim to investigate fundamental research problems associated with the development of sustainable, circular and durable infrastructure materials. Due to the recognised relevance of the scientific work carried out by the PE section, several media interactions occurred, such as in RTL news (2022), Quest (2021) and BNR nieuws radio (2019). In 2021, the PE section organised the International Symposium on Frontiers of Road and Airport Engineering in Delft, on the topic: green and intelligent technologies for sustainable and smart asphalt pavements.

Theme D: Structural integrity through innovative monitoring, damage assessment, prediction and maintenance

The majority of the research work in the following theme is carried out through the MacroLab. To showcase the impact of the ES department within this theme, only few of many projects are described. The Bio-based Structures & Materials (BSM) section runs a project, which started in 2021, and aims at proposing a biodynamic embankment protection. The social relevance of this work can be sought by observing the canal embankments in the Netherlands that all are protected by timber sheet pile walls of tropical timber because of the high natural durability of the timber. This project aims to replace the tropical timber by local, less durable timber in combination with plants where over time the plant roots take over the stability of the embankment. The study leverages on the modelling and field research through a monitoring system that has been installed to monitor the growth of vegetation and the uptake of roots to strengthen the embankment. The CS section provides a further significant contribution within this theme. An example is provided by the AEinCS (Acoustic Emissions in Concrete Structures) project, in which the research is focussed on non-destructive techniques such as acoustic emission for damage detection. For the first time, it was demonstrated that by measuring acoustic emissions from micro-cracks in concrete, it is possible to localise and characterise these cracks and, predict the proximity of a structure's failure even before this can be detected by a visual inspection. Monitoring strategies were also tested and developed, with reference to the long-term monitoring of structural and material properties of the Second Stichtse Bridge built in 1997, starting from which data has been collected on the structural and material performance. The detailed data, and the ongoing periodical data collection (last data set in 2017, expected to be repeated in 2027, 2037 and 2047) are unique in a sense that they give a comprehensive insight in the long-term behaviour of cantilever bridges of high strength concrete. The described projects reflect on several aims (1, 2, 3, 5). At the same time, the impact of research on novel, sustainable, high-performance concrete types and enabling their safe structural application increased. This is demonstrated by the acquisition of an NWO Veni Fellowship, investigating the fundamental behaviour of interface in innovative hybrid concrete structures, and an international Horizon project "AshCycle" aiming to develop more sustainable structural concrete by integrating underutilised ashes coming from waste streams.

6.7 Strategy for the next six years

6.7.1 Introduction to the SWOT analysis

The SWOT analysis of the ES department, summarized in Table 18, and the outcome of the international work visit conducted at the University of Illinois Urbana Champaign (UIUC), form the starting background from which the future departmental strategies were proposed. The discussion of the SWOT analysis starts by first highlighting the strengths, while opportunities, weaknesses and threats will be discussed in combination with the future strategies in section 6.7.2. Among the strengths identified in Table 18, it is worth highlighting that the different research groups contributed to each theme in a complementary manner showcasing the strong cross-link between the staff members and the scientific themes. This was also possible thanks to the extensive MacroLab facilities, which allows each research group to carry out experimental work and span through a large spectrum of different TRLs, ensuring a strong balance between traditional disciplines of structural engineering and the identified themes. Considering the large spectrum of projects, the ES department demonstrated its ability to connect and partner up with major stakeholders in the field of interest, and to secure funding through a good combination of national, European and industry-funded projects. A direct consequence of this, is reflected in the high scientific visibility of the academic staff members, showcased by the indicators reported in Table 17. Besides the research quality, it is worth highlighting that the ES department implemented several strategies to involve early-career staff members in the decision-making process.

While the previous sections emphasised the strengths of the department, in the following paragraphs a more critical view is provided, with reference to the identified weaknesses, opportunities and threats in order to shape the future strategies.

Table 18 SWOT analysis ES department.

	Strengths	Weaknesses
Internal view	• Strong balance between traditional disciplines of structural engineering and new themes of applied research directions • Extensive MacroLab facilities • Excellent partnering with major stakeholders and good mix of national, European and industry-funded projects • High scientific visibility of staff members which are internationally recognised • Involvement of young staff members in the decision making process and departmental life • Strong cross-link between the staff members for different scientific themes	• Long PhD duration • Unbalanced workload between teaching and research • Lack of career path for departmental project managers, which would enable them to manage and obtain new projects • Lack of culture in creating open access data, data management plans, and sharing laboratory-related knowhow • Lack of internal funding for collaborative intra-departmental projects among colleagues.
	Opportunities	**Threats**
External view	• Societal pressure on stakeholders to shift to circular economy and need of safety and security of existing and new infrastructures • Re-organisation of the MacroLab and possible opportunities to attract funding and talents. Thereby increasing the link between modelling and experiment, and intra-departmental collaboration • Embedding new developments in computer science (AI, ML) in Engineering Structures	• Difficulty maintaining highly qualified international research staff and technicians • Difficulty in the acquisition of long-term funding with major stakeholders for certain sections • Maintain the balance between curiosity- and application-driven research • Reduced number of funding schemes favourable to intra-departmental funding to support collaborations across sections

6.7.2 Description of future strategies for the next six years

Overarching aim (1): Strengthen the leading position within the four Themes

All the identified opportunities listed in Table 18, will be beneficial to ensure a leading position within the four themes, especially due to their inherent connection to the societal need to shift towards a circular economy and the need for safety and security of existing and new infrastructures.

The current academic staff will keep growing and rejuvenating, since the ES department intends to open a few specific ACT (former Tenure Track) positions for emerging technologies related to the four themes. In the meantime, the hired early-career academics over the last six years, will have the opportunity to grow and strengthen their leading positions in their respective field of interest, thanks to recently funded projects that will run for the next 3-4 years. As an example, it is worth mentioning the recently funded MSCA-ITN project APRIORI (which kicked-off in April 2023), that will allow two members of the MPS section to reach a leading position and increase their international visibility.

One of the identified weaknesses of the ES department is the recently observed unbalance of the workload between teaching and research, especially due to the involvement within the redesign of the MSc programmes at Faculty level. The ES department already planned a SD for the end of 2023, to review the current teaching workload based on the outcome of the first run of the new MSc programmes and seeks strategies to optimise the current teaching workload.

An identified threat, that could undermine the strengthening of the leading positions within the specific scientific themes concerns the difficulty to maintain highly qualified international research staff and technicians at the ES department. However, to mitigate this threat, strategies should be implemented at a Faculty level. The ES department is aware of this threat and intends to implement more effective strategies to facilitate the integration of recently hired colleagues into the existing context of the Dutch funding landscape, which for Civil Engineering applications is mainly dominated by an industrial money-stream. Before advertising any new academic position, it will be of paramount importance to clearly identify topics able to secure funding. As suggested throughout the international visit at UIUC, the advertised academic positions should then be pitched at relevant universities and conferences, in order to attract talents in a more personalised manner. Once hired, the ES department will involve the recently hired colleagues in joint initiatives led by the existing research groups within the department to facilitate their integration within the national and (international network).

Overarching aim (2): translate research results into effective technologies
The ES department aims at improving and optimizing the close cooperation and co-development of models and tools with the industry in future projects by formulating joint tasks in proposals. As an example, it is worth mentioning the chain of the GDP projects that will be active until, at least, 2027, generating multiple follow ups, thereby making the contribution of the ES department to the energy transition visible and successful. The GDP projects unify the ES department, by seeking collaboration among the sections, and including the MacroLab staff, the majority of whom contribute to the experimental part of the projects significantly. Several industrial partners already joined the projects in the process of their execution. For example, the SIMOX project (6m€ initially) attracted 0.8m€ additional industrial co-funding due to the keen interest of the industry. These partners are aiming at a long-term cooperation with TU Delft and with the ES department in particular. The DSS section also recently applied for a follow-up project GDP2.0 that aims at demonstrating the technology offshore at 50% scale. The aim is to assist in the technology to be market-ready by 2027.

In terms of transferring results into effective technologies, the CS section is already internationally recognised for the acoustic-based monitoring technique, and it is on its way to further integrate and optimise further technologies in the field of monitoring and damage assessment, aiming to maintain their leading position in the field of application, also thanks to a potential increase of the number of field tests, for example in the form of living labs.

The BSM group is actively involved in the development of underwater drilling equipment to assess the state of timber pile foundations. The micro-drilling technique, originally developed for the safety assessment of standing trees is in the implementation phase by the City of Amsterdam, heavily involved in their infrastructure reliability assessment of bridges and quay walls.

The R&R section recently started projects in the fields of Digital/AI-supported/Robotic recycling (Circular Circuits: electronics recycling; DETOCS: concrete recycling; SORTCAS/Reukema: non-ferrous metal and steel recycling; PEACOC: Precious metals and critical raw materials recycling; LICORNE: Lithium extraction from mining ores and tailings) which run for the next couple of years and are being carried out in close cooperation with industries. In some cases, they are being demonstrated in full industrial environment already.

Overarching aim (3): include research activities across different TRLs
Among the opportunities, the current re-organisation of the MacroLab can be used as an opportunity to attract more funding and talents, and potentially leading to a stronger link between modelling and experiments, and to an increase in intra-departmental

collaboration. Overall, fulfilling aim (3) will allow to mitigate the threat concerning the balance between curiosity- and application-driven research. In order to do so, an excellent laboratory facility is needed, which should stem as a direct consequence of ensuring a qualified and dedicated laboratory staff, that can efficiently and safely use and maintain the equipment. It is worth stressing that in the next six years, a significant number of experienced laboratory staff will retire (around 40%) or will be 60+ years old (30%). Considering the new hirings of technicians and the lab's age pyramid, opportunities are foreseen to re-organise the MacroLab, but also threats to the ES department. As mentioned before, the development of strategies to mitigate these threats, should stem from a higher level, possibly at TU Delft level in cooperation with HR. However, suggestions were noted from the international visit at UIUC and the ES department will implement lower-level strategies, to at least ensure the transfer of knowledge concerning the use of the laboratory equipment. For example, knowledge transfer could be ensured by establishing training organised by senior PhD candidates or postdocs to the newly hired PhD candidates or postdocs. Along the same line, new verve will be given to MacroLab, by planning a devoted laboratory space for MSc students, to attract in-home MSc students to our research activities.

Aim (3) refers to reach an optimal balance between curiosity- and application-driven research. At the moment, the ES department operates by taking advantage of application-driven projects to tackle fundamental issues in the traditional fields of engineering. This strategy led to one of the major strengths of the research unit, but threats could also emerge if curiosity-driven research is only moderately supported by the presence of dedicated funding opportunities. To achieve the optimal balance for the ES department, a steady information flow regarding the funding opportunities will be ensured and discussions will be organised to identify the research topics (existing and new) within which we may expect to get funding for curiosity-driven research.

One outcome of a recent curiosity-driven research being followed up by a societal implementation deals with the study into improved embankment stability using vegetation and plant root systems. The technology and its principles were developed under a Marie Curie Training network (TERRE). The technology is now scaled up and put into practise on a test site of 150 m long, together with the Province of North-Holland. In the coming future, the BSM section will invest in the merging of Bio-engineering principles based on plants and plant roots with traditional canal embankment engineering principles, providing structural stability using carbon storing resource wood elements while at the same time minimizing resources, improving biodiversity using carbon sequestering plants.

In terms of future projects able to cross different TRLs, an illustrative case is described related to a recently submitted proposal meant for the Hyperloop technology (i.e. infrastructure, vehicle, network management and control, socio-economic value). to the proposal envisions to connect a large and diverse group of stakeholders (six universities and several companies, societal partners and ministries), and involves three sections of the ES department. Focal points will be the optimised dynamic behaviour of the structure in interaction with the vehicle, but also the development of hybrid structures with acceptable high-frequency fatigue properties and accounting for emission and circularity constraints. Due to the strong societal relevance of the topic, interviews about the role of Hyperloop in society were already provided.[33]

Moreover, two projects in the fields of digitalization of the construction and mining industry (including critical raw materials and rare earth elements) have been filed. These projects foresee research and technology development from TRL 2-3 to TRL 5-6 and are aligned with the EU strategy to become less dependent on raw materials from non-EU countries.

[33] https://stt.nl/nl/over-stt/nieuws/mobiliteit-in-de-toekomst-grensverleggend-hyperloop-onderzoek-splan-van-nederlands-consortium

Overarching aim (4): align the different sections to the four identified Themes
To further achieve this aim for the next six years, it will be important to tackle the weaknesses and threats for the ES department, such as a lack of internal funding for collaborative projects among colleagues and across sections, and an eventual reduced number of funding schemes favourable to intra-departmental funding to support collaborations across sections. The ES department will encourage the submission of joint proposals (i.e. involving multiple sections from the ES department) related to one or several of the identified themes. Those proposals will strengthen the cohesion among the sections, and for which reason financial support will be given to the preparation of such proposals, as to involve professional grant advisors (provided the main applicant is from the ES department).

Moreover, the ES department foresees a closer collaboration between various sections, especially thanks to the research results carried out so far. For example, the CS section will gradually converge part of its research line into theme B, with the aim to develop knowledge concerning the sustainable and safe application of new cement-free and cement-poor concrete types, concrete with alternative aggregates and alternative reinforcement materials at the structural level. Similarly, more time will be invested by the SCS section concerning the development of circular structural systems. For example, a research line that is gradually growing concerns the investigation of the structural performance of steel and steel-concrete composite systems with “low-carbon footprint” concrete for application in circular buildings/infrastructures and tubular sections for the transport and energy sectors. Collaboration between the CS and the SCS section on such topic are foreseen. More collaboration is also expected between the RE and the PE sections, with reference to future-proof embankment stability threatened by extreme weather events and fluctuations in water levels.

Further opportunities to seek alignments among the themes can be exploited thanks to the ongoing trend to embed new developments in computer science (AI, ML) in engineering structures. Members of the PE, RE and MPS sections are already rather experienced in this field of application, pursuing the integration between measurements, physics- and data-based models in order to develop digital twins for accurate life-time predictions of the investigate structures.

Overarching aim (5): growth of an inclusive academic culture
The future strategies described here, also encompass aspects related to the Graduate School, Open Science and Academic Culture. For instance, at the core of the academic culture, the education of future scientists is of outmost importance. To reduce the average PhD candidate duration, a suggestion proposed by the PhD council is to offer the possibility of a paper-based thesis, that could reduce the time needed to prepare the traditional novel-based manuscript.

In section 6.4, the planning of the SD meetings has been described as a worthwhile event contributing to the growth of the academic culture within the ES department. However, improvements will be implemented, especially with reference to a suggestion provided by a research group at UIUC, in which it seems to be a common habit to delegate the definition of future strategies to a dedicated internal committee. The ES department will enforce that after each SD meeting, clear strategies and line of actions are defined and shared with all the staff members, with reference to the topic that has been discussed during the meeting.

With reference to Open Science, the above-mentioned re-organisation of the MacroLab has also the aim to mitigate the identified lack of culture in creating open access data, data management plans, and sharing laboratory-related knowhow. Based on the visit at UIUC, to improve open science practices, the ES department intends to make research results obtained from the MacroLab available, at least internally, but with a future aim to have them available also for a general public.

Overarching aim (6): reach a healthy financial status

The ES department recently introduced a rotating leadership scheme. In such scheme, every senior faculty member serves as section head for three years, and then hands the tasks over to a successor. In this way, over the years, we are expecting an increased awareness of the financial system and risks as well as an environment of shared responsibility. The effects of this rotating scheme will be assessed in the coming year.

Among the identified weaknesses, it is important to stress out the lack of a career path for departmental project managers to manage and obtain new projects in collaboration with stakeholders. This weakness could undermine the healthy financial status of the department in the future. To cope with future funding schemes that will embrace more and more a highly diversified consortium (see NWO-NWA funding scheme), it will be of utmost importance to centralise the role of a project manager in the ES department.

To secure a future healthy financial status, it is worth mentioning the indication provided by our colleagues at UIUC, concerning the financial benefits related to Alumni donation. The ES department is currently exploring the viability of this strategy, especially in relation to potential tax benefits for possible donors.

7. Department of Hydraulic Engineering

7.1 Introduction

Ongoing growth of the world population results in increased pressure on low-lying delta areas and a rapidly growing need for affordable and clean renewable energy. The fast urbanization and infrastructure development associated with this come with immediate consequences for society and the ecosystems we depend on, including increased impacts of major flood events and rapid loss of biodiversity. These impacts are being aggravated by the effects of man-induced climate change.

The department of Hydraulic Engineering (HE) finds itself at the heart of this challenging field. We aim to develop state-of-the-art engineering solutions for high-water safety, nature development, water-born transport and renewable energy, based on a thorough understanding of natural system dynamics, its response to interventions and infrastructure design. We increasingly do so against the broader context of international initiatives like the Paris Climate Agreement and the Global Biodiversity Framework, contributing to several of the UN Sustainable Development Goals (SDGs) including health and well-being (3), clean water (6), affordable and clean energy (7), sustainable cities and communities (11), climate action (13), life below water (14) and life on land (15).

In the global context, the department of HE is unique regarding its size, number of projects, diversity of engineering disciplines and research facilities. The department comprises 12 FTE academic research staff (see Appendix B.1), distributed across five sections (Environmental Fluid Mechanics, Hydraulic Structures and Flood Risk, Offshore Engineering, Coastal Engineering and Rivers, Ports & Waterways and Dredging Engineering) and a Hydraulic Engineering Lab. Research is performed covering the full spectrum of science, engineering and design. Fundamental research is performed to understand the physics of surface wave propagation, open-channel hydraulics, sediment transport, acoustics, and their interactions with the natural environment and/or man-made structures. There is a strong emphasis on maintaining, and further developing, our open-source modelling tools (such as the wave prediction tools SWAN and SWASH and environmental acoustic tools SILENCE and SOPRANO), to synthesise knowledge on these fundamental processes gained from extensive laboratory and field experiments. On the other side of the spectrum, research is performed inspired by applications in the field of hydraulic engineering. This ranges from the evaluation of beach nourishments and measures to mitigate salt intrusion to design guidelines for breakwaters and offshore structures. Our joint research themes are found across the sections and link advances

in fundamental science to real-world applications with key focus on the development of generically applicable modelling tools and design guidance. These four overarching research themes are:

1. Dynamics of marine and fluvial systems
2. Sustainable infrastructure and nature-based solutions
3. Climate adaptation and flood risk management
4. Renewable energy in the marine environment

Themes are directly linked to the Faculty strategy 2019-2024, the core areas of expertise within the Faculty (particularly fluid and sediment dynamics) and cross-department methods and technologies, as shown in Figure 16. The department strongly contributes to all themes by focusing on data collection, interventions, monitoring, risk analysis, uncertainty propagation, numerical, mathematical and physical modelling, and the use of smart materials.

Figure 16 The four Hydraulic Engineering Research themes and four research methods, to have impact in research, education and valorisation.

Given our unique position in the (inter)national academic landscape (as confirmed by the Sectorplan Committee in their first evaluation), integrating science with engineering and design, we feel a strong societal responsibility to play a leading role in the development of innovative solutions for safe and sustainable development of river, delta, and coastal areas worldwide.

This report was compiled by a three-person editorial team consisting of senior academic staff from three different sections, with direct inputs from the department PhD council and department board. Prior to submission, the final draft of this document was distributed amongst all HE staff for review, resulting in several valuable suggestions for improvement.

7.2 Mission and strategic aims of the past six years

The mission of the HE department is to educate world-leading civil engineers, train academic scientists and create scientific breakthroughs by carrying out world-class research. This comprises combining fundamental science with engineering and design, understanding of natural systems and consequences of interventions, developing numerical and experimental tools to validate and substantiate the knowledge, translating and integrating research findings into impactful solutions. The HE department therefore aims at fundamental understanding of relevant processes in rivers, estuaries, coastal seas and oceans. It focusses on evidence-based design/engineering of man-made interventions, both nature-based and structural, in support of safe and sustainable development of urbanised deltas, natural water systems and renewable energy in the marine environment.

Supported by the strategic agendas of TU Delft and the Faculty Civil Engineering and Geosciences, we defined the following strategic aims for the period 2017-2022:

- *SA1: Strengthen the core disciplines that are fundamental to our field*, most notably fluid and sediment dynamics, structural engineering and integral design. Connect to new developments in emerging fields, in particular the application of data-driven technology and machine learning in hydraulic engineering, but also in eco-hydraulics and nature-inclusive design methodologies.
- *SA2: Increase the coherence and interaction between different disciplines and individuals* by providing excellent research platforms for laboratory, field, and computational studies where process understanding can be linked to system dynamics and engineering applications.
- *SA3: Provide an inspiring, safe, and healthy working environment* for our staff, postdocs, PhD candidates, and MSc-students. Enhance opportunities for staff members to build on their career, by regularly reflecting on wishes and needs and by offering personal training for professional development. Deliver structured support and supervision to PhD candidates in order reduce PhD delays, in line with faculty ambitions.
- *SA4: Increase our visibility and impact* at the scientific as well as the societal level. This comprises taking initiatives for defining research agendas at the national and European level, taking leadership in addressing future climate adaptation strategies and developing science-based engineering solutions.

7.3 Follow-up from previous assessments

Both the previous Research Assessment 2011-2026, and the mid-term evaluation resulted in most positive conclusions regarding quality, relevance and viability of the department but also several valuable recommendations for further improvement. This section addresses the key elements of our follow-up, with a particular emphasis on three different aspects: lab facilities, diversity and well-being of staff, and societal impact.

7.3.1 The importance of world-class lab facilities

Both assessment committees have advised to maintain our in-house experimental facilities as a vital basis for research on fluid mechanics and the different engineering disciplines.

Firm action has been taken to secure continuity of existing facilities in the laboratory and to expand on field observations via substantial, multi-million investments in support staff, lab and field instruments, field sites and lab facilities (SA2, further detailed in section 7.6).

7.3.2 Diversity, background and well-being of staff

The previous research assessment committee observed for the faculty that relatively large numbers of PhD candidates, postdocs and Assistant Professors were home-grown. This certainly held for the department of HE. Consequently, the committee felt opportunities were missed to attract diverse opinions, skillsets and interests to the faculty and departments. In addition, the department noted the need to pay attention to staff well-being, most notably the day-to-day workload of teaching staff and the perceived vulnerability of young academic staff in an Academic Career track.
With the hiring of new staff, the department has worked on 'non-Delft' diversity in staff (12 out of 14 new hirings were non-Delft and nine came from abroad) and PhD candidates, as well as on the reduction of workload. Actions were taken to have a stronger involvement of staff department management and organisation. A discussion was started to realise better working conditions (SA3), see also section 7.4.

7.3.3 Societal impact via interdisciplinary projects

The previous committee has stated 'they are convinced that HE can enlarge its impact on the SDGs even more by integrating other aspects in its research, such as agri and food, circular thinking, finance concepts and use of big data, artificial intelligence and social media'. This observation was made for the faculty in broader sense. To further increase the contribution to the SDGs, the committee advised 'Civil Engineering should sharpen its strategic and integral thinking on societal impacts'.
The department clearly acknowledges the importance of this statement and has worked on incorporating SDGs into research projects more explicitly. This particularly holds for the aforementioned research themes 1 (SDG 14 and 15), theme 2 (SDG 11 and 14), theme 3 (SDG 3, 11 and 13) and theme 4 (SDG 7). Obviously not all research can be directed towards SDGs, but a wider scope is encouraged, which is expected to inspire for innovative research (SA4).

The recommendations from previous assessments align well with the strategic aims SA1-4. Yet, they do not give rise to drastic strategic changes to the SA's; instead, they are adopted as key advise on how to remain viable and how to strategically support continuity of our activities at a high level and on relevant topics.

7.4 Strategic process of the past six years

The department has chosen to emphasise its unique strengths on experimental work in lab and field and the broad spectrum of research topics connecting fundamental science to the field of real-world engineering applications. Naturally, a prerequisite for excellence and productivity is a healthy and happy staff and a conducive working environment. In this context strategic aims SA2 and SA3 are most relevant at the department level whereas SA1 and SA4 relate more specific to the research themes.

As emphasised in previous assessments, research infrastructure is considered of key importance. In addition to substantial investments in infrastructure and equipment, specific attention was paid to the organisation of the laboratory and involvement of younger academic staff in its management (SA2). As both the lab infrastructure and equipment are used for a wide variety of projects, it requires a cross-disciplinary and cross-department team to decide on priorities and investments. This was successfully achieved by implementing a department-wide lab committee, representing academic staff (UD/UHD) from all five sections. Besides their direct value for science, laboratory tests and collaborative field work happen to be a key-binding factor in the department creating a conducive working environment as well as an excellent vehicle for research communication and a valuable asset to generate project (co)funding. For these reasons, multi-million investments were made in lab infrastructure, support staff (+2 FTE) and

computer infrastructure (SA2, see section 7.6). Projects with an experimental and/or field-work component are encouraged, and “Topconsortium voor Kennis en Innovatie” (TKI) subsidies are being used as seed money for explorative tests in collaboration with industry.

The department is well embedded in the national and international hydraulic and offshore engineering sectors (SA4). This creates a stimulating environment where societal demands are converted into research questions that will find a fertile ground for fundamental research. Strengthening this position requires strong ties with partners in the sector through joint projects and dual appointment of staff. This connection enables us to link research projects to full-scale engineering interventions and allows to evaluate system response and to develop improved tools such as numerical models and guidelines for engineering and design. To that end, we team-up with partners in multi-disciplinary research projects, in line with the suggestions from earlier assessments.

By participating in advisory boards and public debates we want to be visible and expect to have an influence on the research agendas (SA4). At the other end of the spectrum, curiosity driven fundamental research is stimulated to strengthen the scientific basis of our portfolio, most notably through national science funding (SA1).

Inspiration and productivity thrive by a good working atmosphere, collaboration and support (SA3). The large number of staff members and recent growth of it (from 26 to 39), combined with the tendency to work more remotely, provides a challenge in bringing cohesion in the department whilst caring for individual needs. These developments relate to the second recommendation on staff background and well-being. In addition to the day-to-day interactions in the sections, the frequency of regular staff meetings was increased (from twice per year to bi-monthly) to more intensely inform, reflect and discuss on matters of education, research and organisation on departmental level. An important issue that has evolved from these sessions relates to the Academic Career Track policy in our Faculty. Working conditions for Academic Career Trackers were considered unfavourable for their well-being and productivity. A team was formed to analyse the problem and to come up with suggestions for improvements, which were in line with the earlier mentioned recommendations. The greater part of these suggestions has now been incorporated in the TU Delft policy for Academic Career Trackers. In a similar manner, PhD candidates were invited to propose a strategy to reduce delays in their project.

To further strengthen internal cohesion and facilitate communication amongst staff member (SA2), trainings were offered on teamwork (Insights) and communication practice (empathic communication).

7.5 Evidence

This section provides evidence of quality and relevance of the research outcomes, use and recognition. As a department, we have the ambition to have impact in research and education but also in science and engineering. We therefore consider as ‘products’ of our activities, the educated engineers and PhD’s as relevant as the knowledge and tools. In Table 19, the indicators that HE considers to be relevant are organised along the axes of scientific impact to social relevance and the results of our research in terms of outcome, use and recognition. First, the indicators are described and motivated. Second, the accomplishments at the department level and at the research-team levels are presented. Two case studies are presented in Appendix A.2 representing typical projects on the occurence of flooding (theme 3) and on salt intrusionin low-lying deltas (theme 1).

Table 19 Matrix of indicators of quality and relevance of the research outcomes, use and recognition of the HE department with quantitative estimates achieved during the assessment period in parentheses.

	Scientific Impact	Both	Societal relevance
Outcome	• High-impact publications (70+), • Editorship (30+), • Conference organisation (19)	• Demonstrators/ Prototypes (5)	• Outreach, public debate (10+) • Patents (1)
Use	• Former PhD's working in academia (~15+) • Use of software tools in academia (15+)	• Collaborative research projects with industry (10+)	• Former PhD's and MSc's working in the sector (~200+) • Use of software tools in practice (10+)
Recognition	• Multi-university projects (10+) • Keynote lectures (40+), Masterclasses (15+) • Personal grants and awards (10+) • External PhD committees (50+)	• Collaboration with sector parties on integral design (3)	• Advisory committees (25+) • Implementation of guidelines (5+) • Press and Media appearance (100+) • Awards and decorations (1+)

From the perspective of scientific quality, it is obvious that we communicate on the research outcomes through publications which are considered high impact when cited, on average, more than 10 times/year. Quality is assured by the peer-reviewing process and targeting at journals that reach a wide audience. Contributing to quality assurance in the role of journal editor is a means to set the quality standards. Taking initiatives to bring researchers together by organising conferences is considered a sign of leadership in the research field.

We are convinced that our PhD candidates acquire knowledge and skills that are valuable for their next steps in the academic career. A position in academia is seen as an important way to transfer knowledge and build on the future of hydraulic science and engineering, in The Netherlands as well as abroad.

In addition to publications, much of our knowledge is accumulated and integrated in modelling tools. Usage of these tools in academia shows that it can be considered as state-of-the-art. Unique and high-quality modelling tools also serve as a basis to initiate or join new, multi-party research programs. At the individual level this pertains to invitations to give keynotes and masterclasses as well. Furthermore, being awarded personal grants in highly competitive funding schemes is seen as clear recognition of quality as are professional awards.

From the perspective of societal relevance, we aim to have impact on the hydraulic engineering practice as well as on society at large. This entails communication of our work to the broader community via appearances in regional and national media, and participation to public debates. Patents are seen as a materialisation of research outcome in terms of application.

Since we aim to cover the broad spectrum from fundamental science to engineering applications and design, it is important that our PhD candidates find employment not only in academia but also in the engineering sector. In this way, they bring state-of-the-art knowledge and innovations to practice, but also strengthen the links between department and the sector for future collaborations.

Recognition of societal relevance is reflected in the role our staff members play in providing advice to governmental institutions related to policy making and planning. The same holds for the implementation of guidelines in design handbooks and the uptake of software tools, recognizing the soundness and usefulness for practice. Societal appreciation in the form of awards and decoration is a sign of recognition that reaches beyond professional qualities.

Some indicators carry both scientific as well as societal value, thus linking science to the field of application. We consider this bridging aspect important as intermediate steps are often necessary to materialise ideas at the large scale. Research outcomes are then typically converted into demonstrators or prototype implementations. Scientific knowledge finds its way to the industry effectively with projects that raise scientific questions in a concrete context of application. We therefore consider strategic collaborations with institutes like Deltares and collaborative projects with industry inspiring and important for the application of knowledge. Considering the broad scope of expertise within the department and the aim to develop integral solutions for societal problems it is rewarding if we can play a role at the higher level of policy making and integral design of future infrastructure.

7.6 Accomplishments during the past six years – research quality and societal relevance

This section addresses the performance of the department in the context of the strategic aims and recommendations. Department-wide aspects are mentioned first, with a focus on SAs 2 and 3. Accomplishments related to the more specific SAs 1 and 4 and the outcomes of associated research are presented afterwards, clustered per research theme.

7.6.1 Development of staff and organisation

Maintaining successful research and educational programs requires highly motivated staff and a manageable workload. Since the last research assessment, budget has become available (e.g. Sectorplan, collaboration with sector partners) for hiring new staff (from 8.8 FTE to 12.0 FTE available for research, see Appendix B.1), providing the opportunity for workload reduction and enhancement of diversity (SA3**)**.

This new influx of staff and consequent growth in numbers (from 26 to 39), has motivated us to reconsider the governance of the department, ways of communication and ways of evaluation. The composition of the management team of HE has changed by several replacements with younger staff and representation of research disciplines, laboratories, education and Human Resources (HR). This entailed an update of the Department Organizational Principles (DOP), for instance on the procedure for the nomination of future professors. Several actions were taken to stimulate internal discussion and collect the various opinions of the staff. Explicit attention was paid to the topic of diversity and inclusivity, amongst others by means of plenary discussions during the bi-monthly staff meetings (SA3). A revised, transparent protocol was implemented for the search, selection and interviews of new staff, to avoid possible bias in the recruitment processes. The department HE played a leading role in faculty-wide revision of Academic Career Track policy, most notably the procedure for evaluation and the reduction of the length of the temporary employment from five to 1.5 years. Connected to the MSc curriculum revision, we worked on streamlining the engagement of teaching staff in education, by encouraging teamwork and balanced support from teaching assistants – following a model prepared by our PhD candidates.

Expansion of staff required additional investment in research infrastructure and better alignment of activities particularly in laboratory and field work (SA2). To that end, a HE-lab-committee was formed with representatives of all research groups, securing the financial health of the facilities by strategic project choices, deciding on investments in facilities and equipment and prioritising research activities with respect to funding and availability of support staff, equipment and facilities. In addition to the existing laboratory facilities, substantial expansion in staff and equipment was established to facilitate field work. Multi-million investments were made in new facilities such as the Offshore ice-lab, Multi-physics structures lab, the Fine-sediments lab (joint with Deltares), and future Delta Transport Processes lab. New projects have been initiated and awarded to provided well suited and equipped field sites (Delta-ENIGMA), and to further expand on field surveying equipment (LEAP forward) and qualified technical staff.

It is noted that the diverse, and mostly international, background of the new hires requires time and effort to fully connect and adapt to the Dutch funding culture as well as the specifics of the Dutch water sector. As a consequence, expansion of staff is not directly followed by an increase in the project portfolio. It is therefore expected that in the short term, the department may underperform in terms of finances and project-staff ratio. We realise that ongoing internationalisation also affects the mobility of staff and may have consequences for the duration of appointments in our department.

The accomplishments per research theme (Figure 16) are described below.

7.6.2 Theme 1: Dynamics of marine and fluvial systems

This research theme specifically focuses on the water, sediment and salt dynamics of rivers, estuaries and seas, impacted by a wide range of physical, chemical, and biological mechanisms, and their effects on functions such as flood safety, navigation, biodiversity, and freshwater supply. To serve these functions, we assess the effects of interventions on the water system and provide tools to optimise their design.

To strengthen our expertise in this field, several new staff members were hired, most notably in core disciplines that are fundamental to this research theme (SA1). These include the appointment of a Full Professor in the field of Oceans and Climate (Katsman, internal promotion), an Associate Professor on non-linear surface and internal wave dynamics (Van den Bremer) and Assistant Professors specialised in eDNA for assessing river ecology (Stancanelli) and Flow and transport phenomena in estuaries (Kranenburg, parttime).

New research projects have been initiated and executed to further our understanding of the interaction between the water system and interventions. This starts at oceanic scales to understand and predict the changes in currents and sea levels at global and regional scales as outlined in the recent inaugural address of Prof. Katsman. These affect the transport of heat and salinity but also pollutants like plastic. Given the large scale and remote locations, novel techniques are necessary to monitor the transport of plastics using satellite observations (Figure 17A). Furthermore, the presence of waves further complicates the prediction of the transport pathways for which new lab facilities are being designed and built including a rotating wave-flow tank (Delta Transport Processes Laboratory). At a regional scale, climate induced sea-level changes affect the impact of storms. This is expected to lead to increased dune erosion, run-up and potential flooding. To mitigate these impacts, a better understanding is required of dune and beach erosion under extreme conditions. These extreme conditions are simulated with manipulative field experiments bringing the dunes to the water edge and subsequently measure both the water and sediment motions using a combination of in-house sate of the art in-situ instruments and remote sensing with optical instruments (projects REFLEX/ RealDune). These observation and analyses techniques are also used at sites where

sandy solutions have been adopted to augment or replace existing hard structures both on the seaside (Hondsbossche Dunes), in estuaries (Prins Hendrik Zanddijk, Texel) and in lakes (Houtribdijk, Markermeer) as they can adapt to changes in the environment whereas hard structures cannot. In addition, the effects of vegetation play an important role. This holds for the aforementioned dune systems where vegetation is affecting the dune growth through aeolian transport (Dune Force project) as well as erosion mitigation due to presence of roots but also in other in other ecosystems like salt marshes (Hedwige polder) and mangrove coasts (BioManCo project) where the presence of vegetation and permeable fences leads to damping of the waves, reducing the wave impact and associated erosion during storms (Woody project).

To be able to conserve or restore these habitats in the face of climate change the understanding of the interaction between hydraulic loading, sediment transport, ecology and biodiversity is of paramount importance. This is explored both in controlled laboratory settings, field experiments and numerical modelling with both national and international partners including the use of environmental DNA (eDNA) to assess the potential changes in biodiversity (in collaboration with WUR). Where the rivers meet the sea, the changes in climate, land use and urbanization lead to increased salt intrusion and associated problems for drinking water supply and agriculture worldwide. To combat these problems the SALTISolutions project (NWO-Perspectief, see the case study in Appendix A.2.2) led by Pietrzak, has been initiated with a large team of partners. An important element of this research consists of the monitoring of the salt intrusion using a plethora of sensors in the Rhine-Meuse delta, ports of Rotterdam and IJmuiden and the coastal zone which will subsequently be used to create more accurate predictions over longer time scales to design appropriate mitigation measures. To provide safe shipping in these environments dredging techniques (Water Injection Dredging) are evaluated and fiber-optic based measurements are being used for monitoring as part of the MUDNET consortium that received the prestigious NWO Team Science Award in 2021[34]. Attention is paid to flocculation behaviour of mud by in-situ and lab measurements leading to model implementation in e.g. the Delft3D-model for predictions of nautical depths in ports. At the larger scale of digitization, HE plays a key role in the DIGISHAPE network that deals with the use of AI and Data in the Dutch Water sector.

In addition to mitigating climate induced exacerbation of salt intrusion into the rivers (Figure 17B), measures are required to combat potential large scale bed erosion of channelised rivers by using sediment nourishments and Longitudinal Training Walls for which new modelling techniques are being developed (Rivers2Morrow). Further attention is paid to river responses to the effects of extreme droughts and floods as well as sea level rise. To monitor the changes in river biodiversity due to these kind of human interventions, eDNA is used from reach to catchment scale (Stancanelli). The fundamentals of plastic transport mechanisms are also studied in for riverine conditions with emphasis on turbulence interactions and removal techniques.

Furthermore, collected data and improved understanding is used to establish digital representations of the physical system. This includes the in-house developed SWAN and SWASH models for the prediction of waves and flows that are used world-wide by more than 2500 engineers and scientists, but also more dedicated digital twins like the one being developed for the Rhine-Meuse delta system as part of the SALTISolutions project.

[34] https://www.tudelft.nl/mudnet

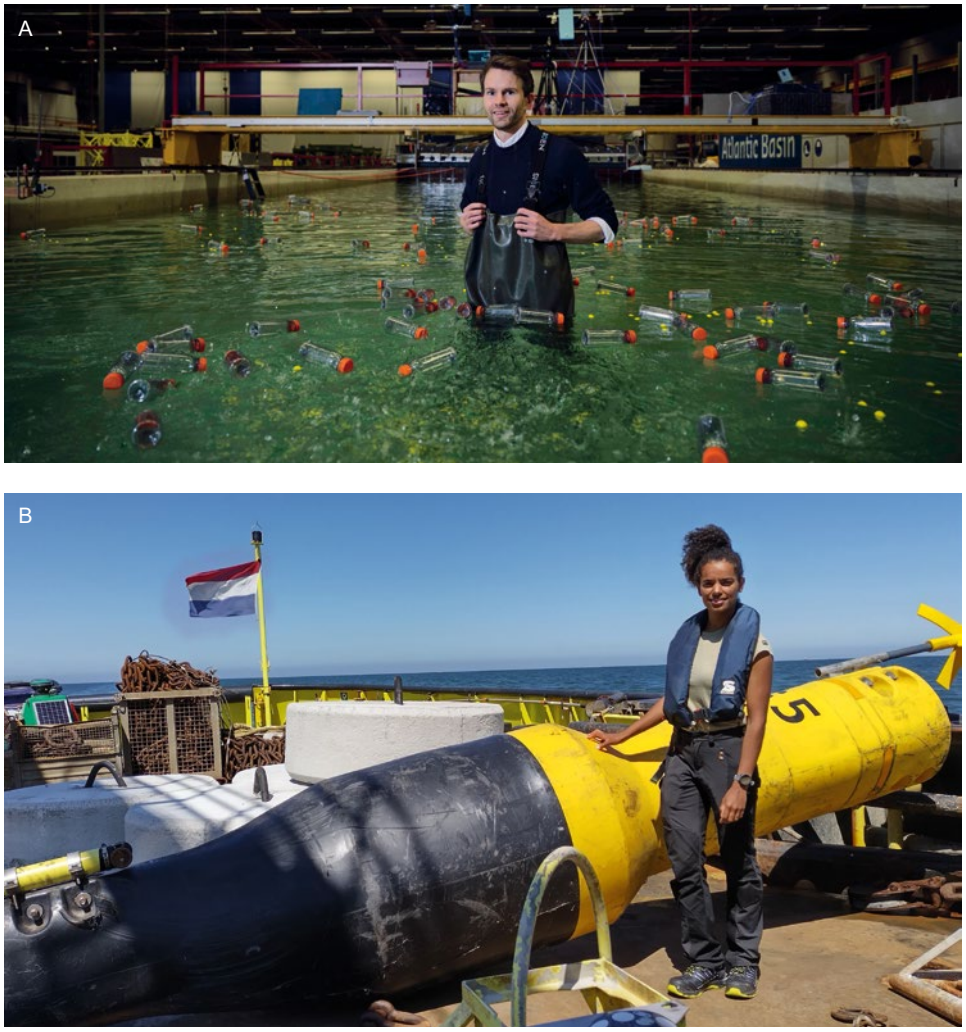


Figure 17 Some highlights of research activities for the understanding of the dynamics of marine and fluvial systems. A) Remote sensing of plastics in the lab at Deltares by Ton van de Bremer. B) In-situ observations of salt intrusion by Tess Wegman (Salti Solutions, picture by Jan-Willem Mol, RWS).

7.6.3 Theme 2: Sustainable infrastructure and nature-based solutions

This research theme focuses on the development and implementation of sustainable infrastructure and Nature-Based Solutions (NBS) for flood protection, navigation, fresh water supply, housing and recreation, in the context of rapid climate change, population growth and biodiversity loss.

To strengthen our expertise in this field, several new staff members were hired, most notably in core disciplines that are fundamental to this research theme (SA1). These include the appointment of Full Professors in the fields of Ports & Waterways (Van Koningsveld) and Coastal Structures (Van Gent), Associate Professors in the fields of Marine Ecology (Van Wesenbeeck) and Seamless modelling of coastal dynamics (Luijendijk) and Assistant Professors on Data-driven technologies for Nature Based Solutions (Antolinez), Port accessibility and sediment management (Kirichek) and Climate robust delta systems (Pearson). Considering the strongly multi-disciplinary nature of the work under this theme, several of these new hires involve parttime appointments, thus strengthening the links with industry (Van Koningsveld) and Deltares (Van Gent, Van Wesenbeeck, Luijendijk) through tangible cooperations. Consolidating its prominent role in fundamental research on eco-morphological processes, research is carried out in the lab on wave attenuation by vegetation to enable resilient and climate-proof coastal protection (also theme 3), in the Netherlands but also in Indonesia and Vietnam. In the

latter two countries coastal protection and mangrove restoration is intertwined with sea-food production and are considered in an integral way (NWO-MuMaCo, see Figure 18A). In the Netherlands the integration is found between oyster reef rehabilitation and offshore wind (ReViFES).

The above projects show that NBS have potential for carbon storage, food production and enhancing biodiversity. The department uses extensive, global data sets, which have shown an incredible growth in availability and accessibility over the last few years, to make an inventory of suitability of and design options for NBS for climate adaptation and disaster risk reduction (VINCARR), for global design of turtle-nesting beaches, and for habitat suitability studies for the Bengal tiger (NWO-NWA Save the Tiger). Sediment dynamics and the role of salt marshes in large-scale natural systems such as the Wadden Sea, Eastern and Western Scheldt but also the Yangtze estuary are studied in the field (e.g. TRAILS).

The effects of climate change and the uncertainties associated with future projections of sea level rise and extreme storm events call for adaptive, landscape-scale solutions for high-water safety. A series of large-scale sandy interventions in coastal, lake and mixed-energy environments has inspired several research projects to study the dynamics of the system (theme 1) but also the effectiveness of NBS in the real world. These include studies on various dune sites across The Netherlands (Duneforce), the Houtribdijk (LakeSIDE) and the Prins Hendrik Zanddijk (EURECCA). The potential for upscaling of such solutions in the context of accelerated sea level rise is explored as part of the C-SCAPE project. New fields that were only recently explored involve the use of NBS to mitigate salt intrusion in estuarine and port environments including their effect on port operations (SALTISolutions project) and NBS elements as part of hybrid structures (EU-LIFE project, Sweden). Each of these projects will contribute significantly to the underpinning and further development of a national-scale vision for climate adaptation named NL2120; they entail intense collaborations with industry, the government, and other stakeholders in the water sector, thus contributing importantly to the uptake of project outcomes in practice and to the societal significance of our work.

In the NWA project PATH2ZERO (PAving THe way towards Zero-Emission and RObust inland shipping), a large consortium led by TU Delft is developing a digital twin to evaluate the effectivity of business models and action perspectives for zero-emission inland shipping. Future energy transition scenarios can be imposed on the digital twin together with proposed intervention measures, based on which the effect of the interventions is assessed. This is achieved in close cooperation with the inland shipping sector.

Much of the research depends on field work and monitoring technology, e.g. based on the development and use of laser scanning techniques (CoastScan project), drone-based video photogrammetry (COCOS-Lab project) and global satellite imagery (CoCliCo project). The many field sites in The Netherlands give the research necessarily a rather Dutch orientation. With the ample experience and strong reputation on field work and monitoring techniques the department has played a leading role together with Utrecht University in acquiring and leading the successful grant application for Delta-ENIGMA, a NWO Large-Scale Research Infrastructure facility to enable ground-breaking, multi-university science projects on bio-geomorphological processes in rivers, estuaries and coastal environments in the years to come.

Fundamental to our approach is a central role for field sites (living labs) as catalyst for national and international collaborations. Tangible pilot schemes and (manipulative) field experiments were found to serve as an excellent framework to encourage multi-disciplinary cooperations such as the unique, large-scale field experiments on dune erosion during annual storm events (RealDune, see Figure 18B) and the effect of natural

foreshores on dike breaching processes, (Living Lab Hedwige Polder). This was also successfully demonstrated in a multitude of research projects at the Sand Motor and Waddensea (SEAWAD and WaDSED NWO-projects), the mangrove coastal protection studies in Indonesia and Vietnam, strategic collaborations with Hohai University and Eastern China Normal University on the theme ‘Coping with Deltas in Transition’ and active engagement in the Coastal Imaging Research Network centred around Oregon State University, University of New South Wales (Australia), the US Army Corps of Engineers and others. Knowledge gained from these collaborations is consolidated in state-of-the-art, open-access numerical models (XBeach, AeoLiS, SWAN). A good example of this is the AeoLiS tool, a novel model for supply-limited, wind-driven sediment transport to the dune areas which has generated a broad and very active global user community with about 300 members.

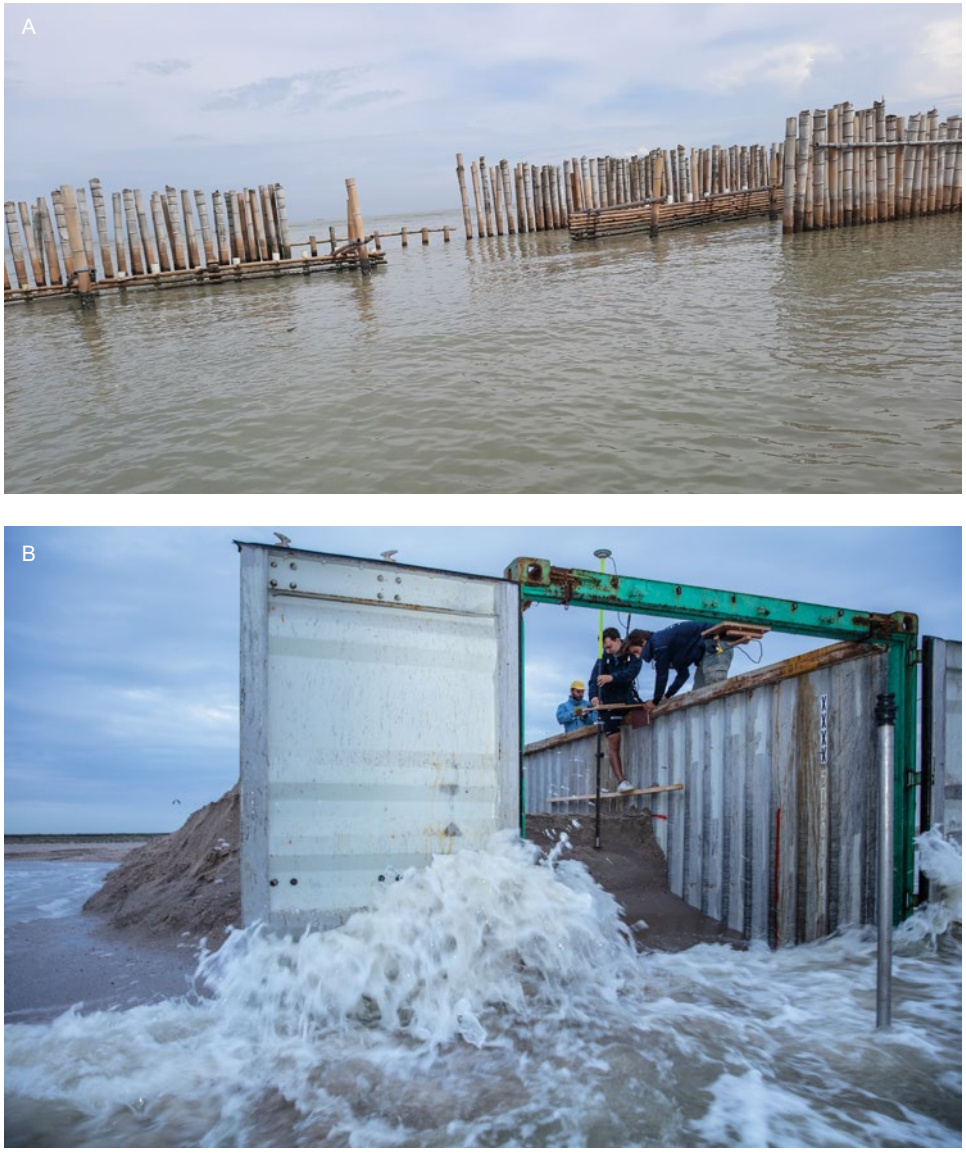


Figure 18 Highlights of research activities for sustainable infrastructure and nature-based solutions. A) Vertical poles reduce wave energy promoting mangrove restoration and opportunity to cultivate native mussels (MuMaCo project). B) Manipulative experiments to examine effects of grain size on dune erosion using sand-filled containers (Real Dune/Reflex).

Along with our prominent role in NBS research comes a highly visible representation in predominantly national but also international boards and frameworks (SA4), including the DIGISHAPE network, Netherlands Centre for Coastal Research (NCK), the Expertise Network Water Safety (ENW) and Netherlands Centre for River Research (NCR).

Strategic cooperations are encouraged through parttime Academic Career track and research appointments with e.g. Deltares (5) and Rijkswaterstaat (2) and other sector partners, and through high-level engagement with EcoShape | Building with Nature (role of Director) and Climate Initiative The Netherlands (vice-chair of Board). The organization of Coastal Dynamics 2021 conference in Delft contributed importantly to our academic visibility. Societal relevance is further achieved by contributing actively to National Park Hollandse Duinen, and our long-year collaborations with the Association of Hydraulic Engineers, “Vereniging van Waterbouwers” and the Zabawas charity fund. Individual recognition was received through the New Scientist Science Talent of the Year award granted to Matthieu de Schipper in 2019.

7.6.4 Theme 3: Climate adaptation and flood risk management

This research theme focusses on the development of methods and strategies for Flood Risk Management (FRM), for today’s society and a future world subject to climate change. This includes the design and engineering of hydraulic structures and adaptation strategies, based on in-depth understanding of failure mechanisms and flooding processes.

To strengthen our expertise in this field, several new staff members were hired, most notably in core disciplines that are fundamental to this research theme (SA1). These include the appointment of an Associate Professor on Structural health monitoring and digital twins (Pregnolato) and Assistant Professors on Hybrid coastal structures (Antonini), Probabilistic assessment of floods and droughts (Ragno), Resilience of hydraulic infrastructure (Wüthrich), and Resilient design for flood risk reduction (Aguilar-Lopez).

In order to be able to realistically assess flood risk and associated damage, floodings are visited post-event where possible, since hurricane Katrina in 2005. For example, the unexpected 2021 river floods caused by extreme rainfall, resulted in high damages (500m€) in the Netherlands, and even more damages and substantial life loss in Belgium and Germany. We took the lead in a national fact-finding study and analysis of the event (see case study in Appendix A.2.1). Several research activities resulted from this initial study such as an invited scientific review and an Interreg research project that focuses on improvement of flood management in the region.

The high population density combined with its low elevation makes the Dutch Delta an interesting living laboratory for climate adaptation and FRM and a showcase for similar areas around the world. Therefore, we have a strong involvement in Dutch flood risk management and Delta planning through representation in advisory boards (e.g. ENW) and review panels (e.g. Delta program). HE faculty has played an active role in discussions in the media on the feasibility and limitations of adaptation strategies to sea level rise, particularly in low-lying polders (NRC Newspaper).

A core focus of our research remains the reliability of defences and development of smart solutions. This is realised in the NWO Perspectief programme All Risk (finished in 2022), in which 18 researchers from five universities participated and which has given scientific insights in the many aspects of the implementation of the flood risk approach. Following-up on this, we have been awarded a new Perspectief programme on Future Flood risk Management Technologies for rivers and coasts for a duration of five years. TU Delft leads this program in collaboration with three other Dutch universities and 28 partners from the sector. Climate change impacts on extreme sea levels are studied as part of the CHANCE project, that was granted under the highly competitive Domain M of NWO.

In smaller projects the details of failure mechanisms of dikes are investigated, such as the monitoring and assessment of backward erosion piping. The “Flood Proof Holland” experimental site brings this to a more realistic scale. The effects of droughts and rainfall

events on levees is measured in situ, supported by STOWA (research organization of the Dutch water authorities). We have participated in the Interreg Polder2C's project which conducted unique safety/failure tests on dikes in the Hedwigepolder. The ministry of Defence has funded TU Delft in a partnership project to further investigate breach closure techniques – the breach defender – which has also been tested at full scale in the Polder2C's project.

In all themes, HE aims to integrate Nature-Based Solutions. In this theme, examples are found in the studies on the use of vegetation for flood protection, in the Netherlands in the form of foreshore vegetation (awarded with the Wadden Academy price2019), and willows (NWO-Woody), and mangroves in tropical areas such as Indonesia and Bangladesh (Worldbank). We continue to broaden and expand the flood risk management approach, also by working with other TU Delft faculties and disciplines, particularly architecture and governance (TPM). In that constellation, HE has been working with international partners (World Bank) for various areas (Mozambique, Texas) to develop models for screening of portfolios of flood risk reduction solutions using public / open access data. Other examples are found in the "Red and Blue" program (NWA) where the real estate sector works together with academia to study the interaction between climate change, flood risk and real estate development. In an even broader sense, we are active in the new national Pandemics and Disaster Preparedness Center (PDPC) with Erasmus-MC on a so-called frontrunner project which focuses on the preparation of the health sector for flood disasters.

Anticipating the changing future sea level and precipitation and storm conditions, a better understanding of the performance of hydraulic infrastructure is needed. The renovation of the 32 km long Afsluitdijk-dam required fundamental knowledge on wave impacts and fluid-structure-interaction at e.g. sluice-gates, which was developed and brought to the level of design in the NWO funded DynaHicS programme. Rijkswaterstaat has commissioned HE to study reliability and adaptability of Dutch storm surge barriers in future conditions and we are in the process of finalizing an engineering doctorate study on a digital twin for the Maeslant storm surge barrier. An innovative hydraulic structure is found in the concept of Submerged Floating Tunnels, involving collaboration with industry in the Netherlands (TEC) and China (CCCC). Three PhD studies on fluid structure interactions and risk assessment have brought this concept substantially ahead. Empirical research on quay walls has resulted in substantial cost savings for the Port of Rotterdam and improved insight in the performance and failure of quay walls in historic cities such as Amsterdam (AMS Institute, LiveQuay). The latter comprised unique full scale failure tests in 2021.

The ports and waterways section is quickly developing into a recognised authority on port infrastructure issues that play at a global scale. Its recently developed textbook 'Ports and Waterways: navigating a changing world' is being used for education at TU Delft, and internationally. Its viewpoints have been reflected in contributions to the Financial Times OECD, and other media appearances. Key elements for Ports and Waterways problems are (1) the ability to quantify the behaviour of complex waterborne logistics in relation to the (changing) physical environment, (2) the design and use of hard infrastructure (quays, locks, bridges, breakwaters) and (3) the design and use of soft infrastructure (accessibility, dredging, land reclamation, beneficial reuse, disposal). Crosscutting themes through these three elements are the themes of sustainability (both regarding emissions and nature-based solutions) and digitalization (data availability, data driven engineering methods, etc).

At the larger integral scale, the department has been involved in international studies on coastal adaptation and protection. TU Delft has collaborated with Texas A&M and Rice University (>50 MSc and PhD candidates) on the protection of the Houston region.

Jonkman has received the prestigious Hagler fellowship from Texas A&M and has spent six months in Houston to do research on the next generation of coastal flood risk reduction solutions. TU Delft aims to play a role in the anticipated R&D activities for the 30B$ “Texas Delta Works” in partnership with local universities and Dutch government and companies.

In line with university open-access policies and to promote academic visibility in this key research theme (SA4), department staff has taken the lead in setting up and managing two new diamond open-access journals focusing on coastal and hydraulic structures (JCHS, Hofland) and coastal and river floods (JCRFR, Jonkman).

Figure 19 Some highlights of the theme Climate adaptation and flood risk management. a) Experiment preparation for testing the effect of flexible ‘vegetation’ on wave run-up. b) Caroline Katsman lecturing at the University of The Netherlands on the effects of changing ocean circulation

7.6.5 Theme 4. Renewable energies in the marine environment

This research theme focusses on the development of novel technologies to enable large-scale energy supply from marine resources (combined wind, wave and tidal). This is considered a crucial step for successfully achieving the transition towards sustainable energy.

To strengthen our expertise in this field, several new staff members were hired, most notably in core disciplines that are fundamental to this research theme (SA1). These include the appointment of Assistant Professors on Fluid-structure interactions (Colomes), Marine and hydro energies (Lavidas) and Offshore soil-structure interaction (Kementzetzidis),

Since the last research visit, our research focus shifted from oil- and gas to offshore wind. Additionally, the research portfolio has expanded further to accommodate solar, wave and tidal renewable energies. In that context, HE has strengthened its research portfolio with unique contributions in marine renewable energy. Particularly in offshore wind, progress has been made in noise and seabed vibration reduction by ecologically friendly pile installation technologies (Gentle Driving of Piles, see Figure 20) combined with computational methods (BubblesJIP, SEASOUNDS). Through smart monitoring of loads and damage the uncertainty in offshore wind systems can be reduced (EUROS). Interaction between sea ice and wind turbine foundations advanced substantially in the SHIVER.

HE has also strengthened its presence on the national research map with projects on floating photovoltaics (RVO - Merganser), flexible wave energy converters (NWO), wave and tidal renewable energies (Dutch-WATERS TKI Deltaworks), and the performance optimisation of low-head tidal turbines (NWO, New Delta).

Collaborations in the field of geotechnics has opened-up new opportunities for research on soil-structure interactions, particularly related to the development of novel cyclic soil reaction models for offshore monopiles in sandy soils RVO-MIDAS and its extension to the interactions of monopiles in clayey soils MIDAS-Clay. Monopile design under seismic loading conditions and associated risk of liquefaction is studied in the NWO-OTP project DONISIS organised in collaboration with the Carbon Trust, and with ETH-Zurich as in the NWO-scheme “Money follows Cooperation”.

The number of successful National and European competitive projects in marine renewables have increased despite the small chances of success which clearly exhibit the strong direction HE has in positioning itself as leader in this field. This fits with the strategy of HE to attract larger amounts of second and third-stream funding, whilst developing an international reputation in marine renewables. We mention several high-profile projects in the next paragraphs.

The ALPHEUS EU-project investigates low-head pumped hydro-energy storage. The VALID project (Verification through Accelerated testing Leading to Improved wave energy Designs) focuses on development of hybrid accelerating testing of wave converters with hybrid testing. The SEASOUNDS project, very recently awarded to HE, aims at an innovative marine soundscape characterization to effectively mitigate ocean and sea noise pollution with a consortium consisting of seven EU universities and a wide industry participation. HE is also a leader in one of the European Commission’s flagship projects for the Energy Transition the European Scalable Complementary Offshore Renewable Energy Sources (EU-SCORES) which will prove that multi source offshore parks with wind-wave-solar will be critical to the future of energy systems. Besides that, HE was also a founding member at WECANet (COST Action 17105, A Pan-European Network for wave energy) with Lavidas being a Working Group Leader and Core Member.

The activities in this theme have resulted in the establishment of new physical research facilities under the umbrella of the Marine Renewable Energies Lab (MREL). The Arctic Engineering Lab (AEL) focusses on ice induced vibrations and structure-ice interactions. The Environmental Vibrations & Acoustics Lab (EVA) focuses on the wave radiation from offshore construction activities and noise induced in the underwater environment.

Figure 20 Some highlights of the renewable energies in the marine environment theme: testing the novel Gentle Driving of Piles (GDP) technique developed at TU Delft (A), measurements of noise emissions from pile installations in the North Sea by Apostolos Tsouvalas and Ozkan Sertlek (B), Field research on Arctic ice in the context of offshore wind by Hayo Hendrikse and Cody Owen.

HE has strengthened the research in advanced computational methods and the development of prediction and design tools for hydraulic and offshore structures (CFSI Lab), with special focus on marine renewable applications. These tools range from numerical methods such as contributions to *Gridap.jl*, the main Finite Element (FE) multi-physics library in the Julia programming language, enabling the combination of FE simulations with other tools from the Julia ecosystem to direct application as engineering and design tools. Tools from HE find valorisation in e.g. the spin-off company, called Delft Cymatics, specialised in environmental impact assessments in offshore wind using the *Underwater Acoustic Simulation Toolbox*. The VANILLA ice model developed by AEL has emerged as the offshore wind industry standard for dynamic ice-load calculations. The SIWED wave energy methodology to assess its potential, developed by MREL, is being incorporated as a suggested method and is currently included in the COPERNICUS “Ocean Status Report” report. MREL is also developing a unique Boundary Element

Method solver, called HAMS-MREL, for multi-body fluid structure interaction problems in marine renewable energies (wave energy and floating wind, predominately). MREL act as a scientific advisor to several National organisations and ministries resulting in recommendations such as the INVEST NL report for wave energy, and TKI commissioned unique open access reports and datasets on the potential of marine energies. The European Court of Auditors (ECA) invited Lavidas to discuss the status of marine (wave-tidal) and offshore wind in the Netherlands, as part of a European Member State evaluation.

7.7 Strategy for the next six years

The four strategic aims that were formulated for the period 2017-2022 have been met to a great extent. Yet, these topics remain undoubtedly relevant for the next six years (representation of young staff in department, reduction of PhD delay, female representation in academic ranks, empathic communication) and will be treated as a high priority aim for the department. While the department achieves great societal outreach and media visibility on technology-related topics (SA4), there is room for improvement in our engagement in the societal debate on climate adaptation strategies and the formulation of associated national and European research agendas.
The process of compiling this research assessment document has stimulated self-reflection, internal discussion, and new ideas how to improve our performance. Further inspiration on that was gained from a visit to the counterpart universities of Leuven and Gent in Belgium, which revealed the following observations:

- Sound management of educational activities is of key importance. Particularly at Leuven University, research staff faces a high education load (up to 30 ECTS/year), to a point where it can be questioned whether the situation is sustainable in the long term. This confirms the importance of a sound balance between research and teaching staff within department.
- Both Gent and Leuven operate dedicated funding schemes to facilitate multi-disciplinary projects, given the fact that external funding for these types of projects is relatively difficult to achieve. This is meant as seed funding to initiate new projects and collaborations, sometimes in conjunction with 50/50 professor appointments at two departments. Besides strengthening links between departments, the goal is also to increase the success rate on EU projects.
- Gent University notes a tendency towards more high-risk PhD projects (several years for experiments and data collection, publication of papers in last year). This is not necessarily perceived as serious problem, if well-established mechanisms to avoid PhD delay are in place. These include availability of a committed doctoral supervision committee, GO/NoGO meetings after year 1-2-3, always multiple supervisors and easy access to an ombudsman within faculty for the PhD candidate if needed.
- Attempts to steer the department project portfolio resulted in limited success only. In practice, PIs (Principal Investigator) individual interests and ambitions were found to be leading in the projects that are being developed. It was proposed to put stronger demands on the broader embedding of projects in department as part of the criteria for promotion to UHD.

The SWOT analysis below (Table 20) is based on both the internal reflections as well as the external observations. It results in the following strategy for the upcoming years.
Our research agenda is inspired by grand societal themes related to climate change, replacement of end-of-life hydraulic infrastructure, energy transition and loss of biodiversity. Recent climate change events that no longer fit with the statistics of long-year datasets, thus challenging hydraulic engineers to design interventions for an inherently uncertain future. This demands the development of completely new design approaches, with a strong urge to start now. HE will pro-actively take initiatives to formulate a coherent research plan (S1, S3). To realise large, multi-disciplinary research programs, it is necessary to improve alignment

Table 20 SWOT analysis department HE

	Strengths	Weaknesses
Internal view	**S1:** Unique and distinctive profile at the interface of fundamental science and application in practice **S2:** The group has been strengthened with enthusiastic and highly qualified new staff, adding to the diversity in terms of gender, nationality and interest. **S3:** Strong research portfolio in collaboration with other universities and research institutes. **S4:** Excellent partnering with water authorities, knowledge institutes, consultants and industry through joint research programs and shared appointments **S5:** High-quality and efficiently organised research infrastructure (labs, flood proof polder, field sites).	**W1:** Duration of PhD trajectories is in many cases still more than five years. **W2:** Some focus areas (river engineering and ports) are still understaffed regarding the educational loads affecting research capacity as well. **W3:** Insufficient use of opportunity to proactively steer the public debate and agenda setting, most notably on climate adaptation. **W4:** International staff sometimes lacks sufficient link to NL sectors **W5:** Not all funding opportunities are sufficiently exploited, in particular international (EU) projects.
	Opportunities	**Threats**
External view	**O1:** Develop leadership in field of multi-disciplinary projects, in context of climate change adapation and renewable energy. **O2:** Increase societal impact through more visible role / representation in media and active contribution to national and international agenda setting. **O3:** Room for growth in use of emerging technologies. **O4:** Room for growth on financial result on projects to enable strategic investments.	**T1:** Lack of societal appreciation in the Dutch society of role of engineers and engineering interventions in solving complex challenges. **T2:** Difficulties to attract good PhD candidates and staff, particularly from The Netherlands. **T3:** Decreasing influx of students in the Civil Engineering program, partially due to competition with alternative programs at regular universities. **T4:** Lack of flexibility to cope with the increasing international mobility of staff.

with national and European research agendas and associated funding (W5). This requires visibility in public debate, leadership in professional organisations and influence in agenda setting and funding decision boards (O1, O2, W3). To meet these objectives, the research strategy can be strengthened by targeted actions (labelled as HE-futures) such as:

- Regularly make an inventory of new developments in society through our network and funding agencies, and update our vision on the needs 10 to 50 years ahead (e.g. through an industrial and societal advisory board).
- Develop and renew a set of indicators and a mechanism for evaluating the societal impact of our work on regular basis, building on the framework presented in Table 19.
- Use outcomes of those evaluations to pro-actively steer on the HE projects portfolio: balance between curiosity-driven versus application-inspired projects and national versus international and achieving diversity in funding agencies.

To realise this research agenda, we aim to strengthen our cooperation with other departments within faculty, with other faculties at TU Delft (most notably Mechanical Engineering, Architecture and Technology, Policy & Management) as well as other universities and external parties (Deltares, Rijkswaterstaat, industry & consultants, WWF, Worldbank). These collaborations are a prerequisite for integral design and engineering of climate adaptation and energy transition measures (S3, W5). It is noted that successful,

multi-disciplinary cooperation goes beyond ‘simply bringing disciplines together’, thus posing strong demands on the collaborative environment and staff competences to create a true spirit of co-creation. HE wishes to take the lead in this as part of the larger Contours2030 TU Delft growth strategy, along with stronger embedding of the integral/ multi-disciplinary perspective in CEG MSc programs to boost growth of student numbers in these fields (T1, T3).

Besides these integral ambitions, it remains important to maintain in-depth, mono-disciplinary knowledge and models to safeguard the fundamental basis of fluid mechanics (waves, free-surface flows, rheology, ice, turbulence), sediment dynamics (mud, sand, gravel, morphodynamics), ecology, structural engineering and acoustics. To properly balance the multi- and mono-disciplinary research and to build on our knowledge base, we encourage acquisition of prestigious personal grants at all levels, nationally (NWO-Veni, Vidi, Vici), and European (ERC, Starting, Consolidator, Advanced) (W5). We are working in a data-rich environment, partially made available by others, partially generated by our own research. The connection between data and modelling, as well as assessment of uncertainties and probabilities will remain an important part of our work. HE will further develop advanced modelling tools, digital twins of deltas and seas (e.g. DIGISHAPE) with incorporation of advancements in AI where possible (O3).

Given the current financial situation and expected growth of salary costs in the upcoming years, we will continue to pay attention to sustainable project finances. This starts with realistic budgeting of costs in the project proposal phase and careful selection of funding schemes and sponsors (O4). More staff engagement on projects, pro-active budgeting of facilities on projects, improved discipline in time keeping and better project conditions will all contribute to the realisation of a better financial result on projects.

Irrespective of the research agenda, successes are to a large extent depending on the motivation and well-being of our staff members. This requires balancing department ambitions with workload, and teamwork with individual ambitions (W2). Within the boundary conditions of the university and faculty, HE facilitates and stimulates individual development and career paths acknowledging the individual talents and differences. This, for example, also comprises Dutch language courses (W4). Cross departmental interactions, such as regular meetings, workshops on research and personal skills and leadership development will contribute to internal cohesion. By giving the younger staff a more influential role in the management of the department, involvement and shared responsibility are stimulated. By creating an attractive and conducive working environment with perspective to grow regardless of function, we expect to form an inspiring and inclusive community that has a significant impact in research, education and society (T2, T4, W1).

The writing of this document and the input received from the staff members inspired for follow-up actions. We will use this research assessment document and the outcome of the evaluation to initiate strategic discussion sessions within department centred around the four research themes. Guided by the strategic elements listed in this section, each research theme will formulate answers to questions like ‘what do we wish to achieve in the next six years’, ‘how will that be done’, ‘what collaborations are needed to get there’ and ‘which projects should be developed’. Re-definition or expansion of our research themes can be an outcome of these sessions, if deemed necessary. We anticipate these sessions will facilitate further staff engagement with department and encourage strategic discussions in department in the years to come.

8. Department of Transport & Planning

8.1 Introduction

Transport and mobility are critical in modern societies: they provide access to goods, services, and job opportunities, promote economic growth, and facilitate social interaction. They play a crucial role in improving people's quality of life and enabling economic development. At the same time, transport has negative effects such as pollution, traffic congestion, accidents, impact on land use, and economic costs, which can harm the environment, public health, and quality of life. Our goal is to develop sustainable solutions that address the complex challenges facing transport and mobility in modern societies in the best possible way by researching beyond-state-of-the-art methods and technologies. The research lab-based organisation of the department aims to contribute to this objective by means of several thematic labs that focus on different societal challenges identified in the Faculty strategy, and methodological or mode-agnostic labs that develop and/or work with state-of-the-art methods and technologies. Our lab structure with 12 labs occupies the middle ground between a section-based hierarchal structure and a Principal Investigator (PI) model (see section 8.4).

Transport & Planning (T&P) addresses four main themes. The first three themes A-C are linked to the Sustainable Development Goals (SDGs)[29], while the fourth theme D includes the main methodological and technical challenges the department has addressed:

A. Urbanisation and Smart Sustainable Transport. This theme is focused on creating sustainable and smart transport systems that prioritise efficiency and accessibility in urban areas. It links directly to the SDG 11 – *Sustainable Cities and Communities*[35]. It includes topics such as Mobility as a Service (MaaS) and Mobility-on-Demand, safe and sustainable active mode transport, low-car cities, electric and automated urban mobility, emerging urban transport technologies and services, and coordinated and connected traffic management.
B. Climate-friendly Transport and Resilience. This theme is focussed on creating transport systems that are resilient to climate change and prioritise low-emission and sustainable modes of transport. It links directly to SDG 13 - *Climate Action*, and indirectly to SDGs 7 - *Affordable and Clear Energy,* and *12 – Responsible Consumption and Production*. The theme includes topics such as sustainable multi-modal traffic management, electrification of transport, and resilience in traffic and transport.

[35] SDG 11 is to "Make cities and human settlements inclusive, safe, resilient and sustainable."

C. Well-being, Health, Equity, and Digitisation in Transport. This theme is focused on creating transport systems that prioritise the health and well-being of all individuals, promote equity and accessibility, and utilise digitisation and automation to improve the efficiency and effectiveness of transport services. It links to SDGs 3 - *Good Health and Well-being*, *4 - Gender Equality* and 10 - *Reduced Inequalities* and encompasses topics such as the interaction between land use and transport innovation, traffic and transport safety, and equity and inclusiveness in transport.

D. Computational Modelling and Analysis for Transport Engineering. This theme focusses on the use of numerical modelling, simulation, and Artificial Intelligence (AI) to solve transport engineering problems and design systems. It also covers the use of sensing, monitoring, and data analysis techniques to inform the models and simulations, as well as the use of risk analysis and uncertainty quantification to develop robust and reliable models.

The themes reflect the transition T&P has made in the past decade in terms of the focal points of its research, as will be discussed further in the remainder of this report. Table 21 below shows how the research performed at our research labs links to the themes. A more detailed overview of the topics considered per theme and how these relate to the labs can be found in the Table 35 in Appendix. C.3

Table 21 Overview of themes and topics in relation to the research labs. The numbers indicate the relative importance (on a scale of 0-100) of a specific topic for a T&P lab (i.e. in terms of research effort spent). We refer to Fig. 21 where all abbreviations are defined.

	Thematic labs						Mode-agnostic labs					
	AMLab	SPTLab	DRTLab	hEATlab	TDMac	F&L	TTS	UMO Lab	MXR Lab	SUM Lab	DittLab	AIM Lab
A. Urbanisation and Sustainable Transport	◉	◉	◎	◉	◉	◉	◎	○	●	◉	●	◎
B. Climate-friendly Transport and Resilience	◎	●	◉	●	○	◉		○	○	●	○	●
C. Health, Equity, and Digitisation in Transport	○	●	▪	▪	○		◉	○	●		●	
D. Computational Modelling and Analysis for Transport Engineering	●	●	◉	●	◉	●	◎	◉	◉	◉	◉	◉

0% ○ >5% ◎ >20%

▪ >1% ● >10% ◉ >30%

The current report was written and edited by one Assistant Professor, one Associate Professor and two Full Professors including the Department Chair of the T&P department, as well as the Executive Secretary. The main input was collected through specific requests sent by email. Different group meetings were organised, and three members of the writing team and the HR Advisor visited the University of California, Berkeley (UCB) for a comparative assessment.

8.2 Mission and strategic aims in the past six years

8.2.1 Mission

T&P is a global leader in transport science and engineering, providing top-level education and world-class scientific research to develop knowledge and tools for sustainable and resilient multimodal transport systems for people and goods. Through our multidisciplinary research, we strive to address critical societal and mobility-related challenges such as urbanisation, climate change, and the transition to renewable energy, while promoting

well-being, equality, and inclusiveness. We pride ourselves on creative and responsible breakthroughs, and our work at the global forefront of transport science and engineering drives us to make a positive impact on the world.
The department aims to leverage its extensive expertise in advanced traffic and transport models and methods to turn data into actionable insights and evidence, creating tools that enable stakeholders to make more sustainable strategic and operational decisions. We understand the importance of having a research team with diverse expertise and a deep understanding of the complex systems involved in tackling today and tomorrow's grand challenges in transport and mobility. That is why we have invested in growing our research team, ensuring that it is well-versed in both the technical and societal aspects of our field, as will be discussed in section 8.6.1. Through our lab structure, we have fostered cross-theme collaborations, enabling us to address these challenges by adopting a holistic and interdisciplinary approach.

8.2.2 Strategic aims

The strategic aims of T&P underlying our activities during the assessment period can be summarised as follows:

- Maintain our international top position in traffic flow modelling, seamless multimodal transport, automated driving, cooperative and connected network management, and network reliability and robustness, also in relation to climate adaptation.
- Maintain and strengthen our prominent international position in experimental and empirical research, investing in Virtual Reality (VR), data collection and management, and experimental facilities.
- Increase and broaden our societal impact, e.g. through regional and national collaborations, increased emphasis on EU projects, and staff training via the Societal Impact Factory (SIF, explained in section 8.3.1) and the lab structure, which encourages academic entrepreneurship, including long-term relationships with partners.
- Increase our scientific impact on new methodologically and / or societally relevant fields, e.g. a) Explainable AI in transport and logistics; b) eXtended Reality for mobility research and engineering; c) Digital twins and digital ecosystems; d) (Digital) equity, inclusiveness; e) Electric mobility and climate change mitigation and adaptation; f) via hiring new staff / establishing new labs, joint cross-department initiatives initiated by existing labs.
- Advance our research programme on sustainable and resilient transport of people and goods.
- Increase opportunities for and responsibility of younger academic staff via our novel labs-based department structure.
- Ensuring a safe, healthy, respectful, and inclusive working environment for all members of the T&P department.
- Promoting cross-faculty collaboration, e.g. via the Transport & Mobility Institute (TMI).
- Capitalise on existing link to AMS (Amsterdam Institute of Advanced Metropolitan Solutions)[36] and strengthen links with Erasmus University, and Leiden, via Convergence[37], i.e. the Resilient Delta programme and the Pandemic and Disaster Preparedness Center.

These strategic aims are well embedded in the Faculty strategy: T&P contributes to our shared mission to create a better living environment for society by conducting fundamental, application-inspired research, engineering and design, and providing innovative and comprehensive engineering solutions. Research themes cover faculty-wide themes including impacts and opportunities of urbanisation, climate change mitigation and adaption, and renewable energy. The research agenda is also well aligned with the scientific themes Climate Action, Energy transition, Digital Society, and Urbanisation & Mobility, as well as the focus on living labs, which have been identified as strategic priorities of the TU Delft.

[36] www.ams-institute.org
[37] https://convergence.nl

8.3 Follow-up from previous assessments

In this section, we summarise our actions in response to the feedback from the research assessment 2011-2016 that had the most significant impact on our research strategic aims and overall strategy. The quotes below refer to passages in the Research Review report (page 22-23).

8.3.1 Towards a broader societal impact

One way in which the lab structure has been instrumental is in “increasing T&P’s potential impact by extending the present research focus on efficiency and by paying stronger attention to the spatial impact of transport solutions, knowledge transfer to design components, and safety and sustainability” as suggested in the previous assessment. With the establishment of the T&P labs, the themes covered have broadened, while the links to the relevant SDGs have been explicitly established. T&P has initiated the Societal Impact Factory (SIF), which offers coaching and intervision to improve researchers’ skills to identify societal needs and create tangible societal impact through the theory of change. T&P has successfully worked on increasing its involvement in large projects that go beyond making mobility more efficient, including topics dealing with “ethical and institutional questions related to automated driving”, e.g. via participation in several Horizon Europe programmes (e.g. HiDrive).

8.3.2 Training and coaching junior faculty

The assessment committee challenged T&P to ensure that “senior faculty members mentor junior colleagues on how to balance quantity and quality with regard to their career development” to reduce “a focus on quantity rather than on quality”. Within the broader topic of academic impact and leadership, the issue of quality versus quantity is addressed during the annual Result & Development (R&D) cycle via the instructions provided by the department head. Academic Career trackers have monthly coaching sessions with their managers. Despite these and other efforts, there is still a tendency among younger academic staff to take on too many tasks and responsibilities and supervise a large number of PhD candidates. T&P is committed to addressing this issue, partly with a view to promoting a healthier work-life balance and well-being. The labs are also instrumental to “improve international exposure of junior faculty members”. The labs regularly organise symposia and seminars and often invite international speakers to give keynote addresses. T&P encourages junior scientific staff to present their work at international conferences and provides support. While T&P recognises that our staff feel that their high workloads impede them from going on extended stays/research sabbaticals, T&P supports longer research visits and research sabbaticals for all its staff members.

8.3.3 Better integration of T&P with other departments

By working on Faculty-wide themes such as urbanisation, climate change adaptation, and renewable energy, T&P has improved its integration with other departments of Civil Engineering within the Faculty. The foundation of six mode-agnostic or methodological labs has shown that, apart from there being a joint interest in solving pressing societal challenges, the techniques and methods used in the T&P research domain are highly relevant for other departments. This has already led to collaboration in education (e.g. the Modelling, Uncertainty, Data for Engineers (MUDE) module), and shared research facilities (e.g. the shared use of VR facilities by T&P and 3MD). Furthermore, the department collaborates with Engineering Structures via the TU Delft Rail Institute. In this way, we have “strengthened integration with other departments in CEG” in addition to existing collaborations with Ports & Waterways (leading to three finished PhD projects).

8.3.4 From an inside-out to an outside-in perspective

T&P has developed new instruments for matching its research agenda with the societal and scientific needs: for one, the lab structure better equips T&P to collaborate with

relevant stakeholders and, supported by the SIF, ensure that the labs' research agendas correspond with societal needs. Secondly, for decisions on portfolio extensions at the department level, a taskforce has been set up that allows lab directors to put in proposals about strategic investments in research staff. Thirdly, the T&P department has invested in taking up strategic roles in agenda-setting committees (e.g. Raad voor de Civiele Techniek, Klimaat Initiatief Nederland, steering committee CBR[38]). Fourthly, in addition to contributing to the research strategy of the Faculty and the identification of the Sectorplans, T&P takes a leading role in setting the mobility research agenda via the TU Delft | Transport & Mobility Institute. T&P uses budgetary space to strategically fill new positions, reconsidering profiles of academic staff upon retirement or when they leave the T&P department.

The assessment committee warned T&P to "become more self-critical in order to stay world-leading". In the assessment period, we have used this feedback in multiple ways: by working on improving the SWOT, by (continuously) collecting feedback from our key stakeholders (e.g. via the SIF), and via multiple intermediate internal assessments of the T&P department on specific topics (e.g. organisation structure, well-being).

8.4 Strategic process of the past six years

8.4.1 Organisational structure

The T&P labs work on topics that fall under the four T&P themes described in section 8.1. The horizontal labs in Figure 21 emphasise the mode-agnostic, methodological aspects of the T&P domain (e.g. data collection, modelling, optimisation, AI), while the vertical labs focus more on thematic topics (linked to SDGs) and modes of transport. The labs are co-directed by two faculty members who hold the ranks of Assistant, Associate, or Full Professor. They are responsible for defining the lab's mission, strategic aims, and overall strategy, all of which are aligned with the department's overall mission, vision, and strategy. Typically, the labs consist of PhD candidates, postdocs, other faculty members, and researchers who conduct research within the lab's domain. The labs have the autonomy and the responsibility for organising and funding their own research

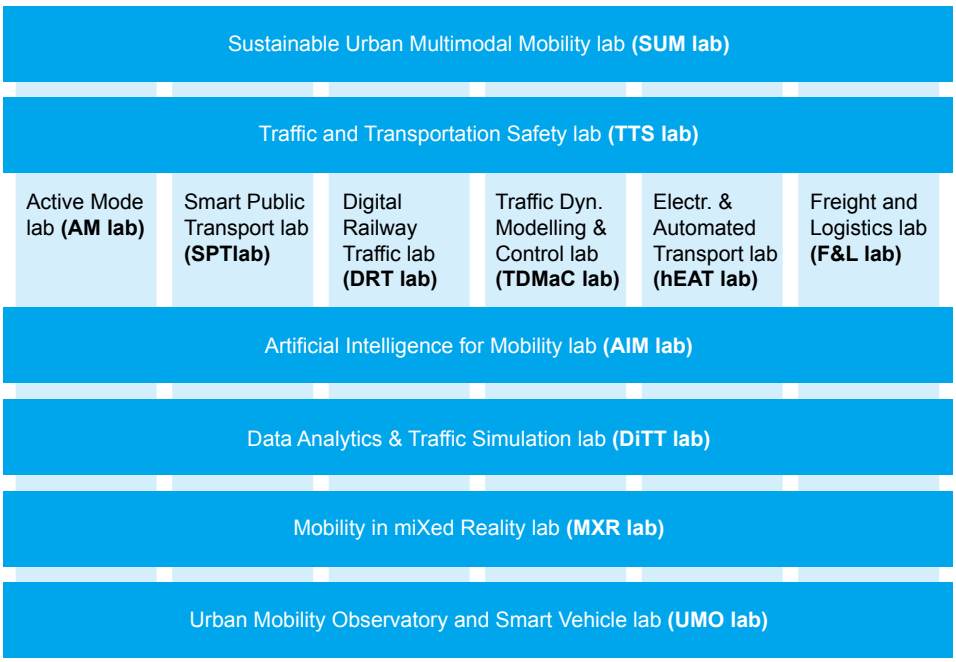


Figure 21 Overview of the 12 T&P research labs, distinguishing between vertical (thematic) labs and horizontal (mode-agnostic, methodological) labs.

[38] Dutch organisation responsible for administering driving tests to the general public as well as professional drivers.

activities, including dissemination, as well as recruiting PhD candidates and postdocs, for which the directors have HR responsibilities. The labs develop funding strategies to best suit their domain, such as a greater focus on either application-oriented or more fundamental research and associated funding opportunities. The lab directors engage in monthly intervision through a meeting known as the Overlab (Overleg Labdirecteuren). During these meetings, directors share experiences and discuss issues related to running the labs, new calls and initiatives in which they can collaborate. The Department Chair, Hoogendoorn, and co-chairs, Cats and Van Arem, also participate in the Overlab. The chair of the Overlab (Goverde) represents the lab directors in the department's MT.

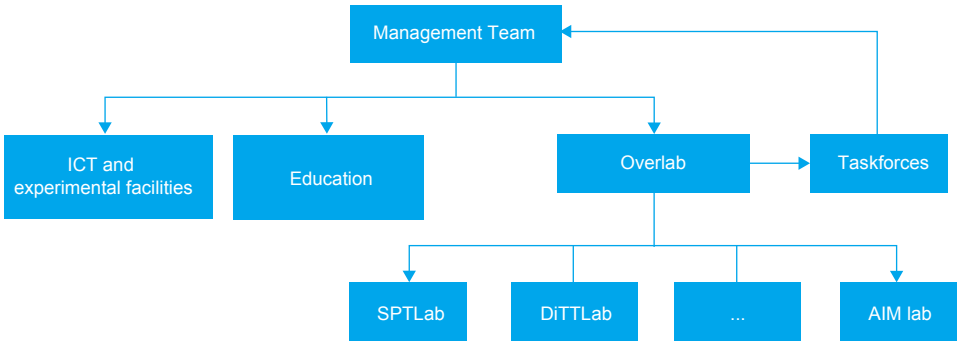


Figure 22 Organisation diagram showing MT, Overlab and role of Taskforces.

Figure 22 depicts the organisational structure of T&P, with the Management Team (MT) being responsible for overseeing day-to-day operations within the T&P department. The MT comprises the department chair and co-chairs, the department's executive secretary, the education coordinator (coordinating the teaching activities in which the department is involved), the coordinator of T&P's experimental facilities, the chair of the Overlab, representation from the student body, and representation from the PhD candidates. The MT meets every two weeks, making decisions regarding the profile of new staff, new positions, annual budget, and strategic investments.

The MT or the Overlab can (jointly) establish Taskforces to address strategic topics. Taskforces provide solicited and unsolicited advice to the MT on various issues. The taskforces are composed of multiple volunteers and tackle topics such as well-being and workload, social safety, knowledge security, sustainability of T&P mobility, and departmental organisation. They also provide input on profiles for new positions.

8.4.2 Open science

We strongly believe in the principles of open science and follow the faculty guidelines described in chapter 2. We are actively involved in developing and integrating shared and open research resources such as data, data collection technology, and data processing code. All PhD candidates share their data to the extent that privacy and ethics requirements allow. Data collected on and around the TU Delft campus via the Outdoor Mobility Digital Twin (OMDt) are made available to all researchers at CEG and TU Delft, as well as to partners of the UMO programme. The UMO Lab, the DiTTLab, and the AIM Lab spearhead our open-science approach. Finally, the Transport & Mobility Institute (led by Van Arem until 2022; who was succeeded by Hoogendoorn in 2023) has the objective to establish shared research facilities, which further demonstrates our commitment to open science. T&P is also making strides for joint research and knowledge dissemination with low-income countries, such as by providing training on sustainable public transport and traffic safety. The AFROsafe project aims to propagate a Safe System approach within the road safety work context in African countries by exposing local practitioners and decision makers to state-of-the-art knowledge and best practices and developing tools and methods to improve road safety.

8.4.3 PhD Policy and Training

a. PhD education and training

The PhD candidates at TU Delft and the Faculty of CEG are welcomed by the Faculty's Graduate School. The PhD candidates at T&P also participate in TRAIL, the Netherlands Research School on Transport, Infrastructure, and Logistics (see Appendix D for a detailed self-assessment). Accredited as a research school since 1997, TRAIL is a collaborative initiative of six Dutch universities. In addition to training, the school provides PhD candidates with the opportunity to present and discuss their proposed, ongoing, or finished work with their peers, exploring common interests and making plans for joint work in the future.

b. Supervision, mentoring, and coaching

The department seeks to foster excellent supervision, which is monitored via the yearly progress meeting reports by the department chair and the director of the graduate school and discussed in the Half-Yearly PhD Progress Report (HYPPR) meeting. The department furthermore recognises the importance of PhD well-being and has a buddy system in place, where senior PhD candidates peer-mentor PhD candidates. A professional coach has been hired to work on the well-being of PhD candidates, emphasising the importance of their overall welfare. Moreover, the labs are designed to provide PhD candidates with a supportive environment: they are large enough to facilitate connections with other PhD candidates and staff members, but small enough to prevent PhD candidates from feeling overwhelmed. During the COVID pandemic, special attention was paid to PhD candidates' well-being. This included offering opportunities for remote and in-person social interactions, ensuring regular communication, and providing information on support options.

c. Expectation management

To enhance the PhD completion rate, T&P has implemented a range of activities based on a broad survey conducted among PhD candidates, followed by several meetings with the students and their supervisors. These meetings aimed to identify the main causes for delays in the research process and to synchronise expectations between the candidates and their supervisors. This problem-scoping activity has already fostered mutual recognition and awareness of the challenges that can arise during PhD research. One of the concrete actions taken in response has been the provision of PhD thesis department guidelines. These guidelines provide clarity on what is expected from a PhD candidate in terms of contributions to science and provides guidance on how to structure a dissertation. PhD candidates are strongly encouraged to develop their research plans, while keeping in mind the requirements in the guidelines, with a focus on research phases, research products (papers, data, software products), and coursework. Examples of good research plans are shared.

As part of department policy, PhD contracts are, in principle, not extended beyond four years, even if funding for an extension can be secured. Exceptions are made for DAILab PhD candidates (who are heavily involved in teaching and therefore get a 5-year contract), and extensions made due to COVID-related delays.

d. PhD representation and organisation

PhD candidates are also given more opportunities for representation in the department's MT, and the PhD council at the faculty and university level. These avenues allow PhD candidates to influence university policies on subjects that are important to them, ensuring that their voices are heard. The Sparks meetings, open to all members of T&P, provide means to hear from the MT directly on specific topics, as well as opportunities to share or "spark" research, ideas, and concerns. PhD candidates meet in monthly PhD meetings.

8.4.4 Academic Culture

a. Openness, (social) safety, and inclusivity

In line with the rest of the faculty, we are committed to an open, safe, and inclusive workplace. This is reflected in several practices, such as raising awareness of social safety and inclusiveness issues through the annual assessment and development meeting, where social safety is a key consideration. Through the participation of Martínez in the Diversity and Inclusion (D&I) committee, the department is involved in Faculty-wide diversity and inclusiveness activities led by the Faculty D&I Officer. The well-being task force considers social safety a topic that requires department-wide discussion and ensures that it is on the MT agenda. Finally, applicants for positions at T&P are asked to provide a diversity and inclusiveness statement, which is considered during the hiring process. Several staff members have completed Empathic Communication training.

b. Research integrity

T&P acts according to Faculty-wide policies and (PhD) training (e.g. via the Graduate School courses on research competences and skills), as well as following common best practices when conducting its research, in line with the five principles laid down in the Netherlands Code of Conduct for Research Integrity. T&P takes special care to comply with the ethical aspects of working with human research subjects, which means, for instance, that before collecting data, plans are submitted to TU Delft's Human Research Ethical Committee, of which one member comes from the T&P department. Research data are shared according to FAIR principles (see section 4.4.2 for more information).

We do not have an explicit policy regarding authorship: we believe that the leadership of our academic staff results in responsible authorship practices. We emphasise the importance of ensuring that all authors listed on a publication have made a considerable contribution to the work. Our culture of authorship aligns with international standards and guidelines. We foster a research culture of honesty, fairness, and accountability. Moreover, we encourage younger staff to publish without their direct manager.
T&P, which has various collaborations with Chinese universities, recognises the importance of knowledge security and research autonomy. We have established a taskforce to address these issues and have made it a priority to raise awareness on the topic during meetings of the MT and the Overlab. To ensure a comprehensive approach to knowledge security, we have gone through the process of "moral deliberation" for several issues (e.g. continuation of our shared BSc program with BJTU, collaboration with Chinese technology companies). By taking proactive measures to safeguard our knowledge and research autonomy, we aim to ensure that our collaborations with Chinese universities are mutually beneficial and sustainable.

8.4.5 Human Resources Policy

T&P values diversity and strives to achieve it on various fronts. There is a mix of backgrounds in the broad field of T&P, with thematic, applied scientific backgrounds alongside more methodological ones. More teaching-oriented career pathways are also possible, in line with TU Delft policy. Much effort has been put into recruiting new female faculty members, with T&P actively seeking out and approaching talented female scientists, sometimes using closed selection procedures. Our approach has resulted in a high influx of female staff during the assessment period (section 8.5). The department has strived to build a healthy blend of junior, medior and senior staff (section 8.5).

Our recruitment strategy for new faculty is based on four pillars:

- Setting up strong profiles for candidates: we believe that setting up strong profiles for candidates is a critical first step in our recruitment process. We focus on specific themes, such as climate, AI and mobility, and resilience, but we formulate these themes broadly to cater to candidates' personal vision. We also reconsider and revise profiles if vacancies arise to ensure we maintain a diverse and dynamic team.

- Actively recruiting young talent: we actively recruit young talent through our extensive network, which allows us to identify and approach promising candidates. In some cases, we may conduct brief interviews before inviting candidates to apply for an open vacancy. We may also consider a closed procedure, depending on the specific circumstances.
- Providing a vibrant working environment: T&P offers a working environment that provides unique opportunities for collaboration with peers through our lab structure. Our labs also offer excellent means to develop academic leadership and entrepreneurship skills. We provide our faculty with a supportive environment that fosters academic excellence and personal growth.
- Maintaining a strong reputation for academic excellence: T&P has a strong reputation for academic excellence, and we are committed to maintaining this reputation through our recruitment process. We seek out candidates who are passionate about their field and who demonstrate a commitment to advancing knowledge through innovative research, creating impact, and enhancing teaching methods.

By incorporating these elements into our recruitment policy, we ensure that we attract the best possible talent and provide them with the resources and support they need to excel in their field. Note that we actively seek opportunities to fund strategically important positions (e.g. in climate, resilience, and applications of AI and Mixed Reality) through initiatives such as the Sectorplan (for explanation see 1.4.3.d), and through the cross-departmental and cross-faculty programmes on Sustainable and Resilient Transport of Persons & Goods, supported by (seed-)funding from sources such as the Transport & Mobility Institute.

Through the annual R&D cycle, we can ensure that our staff members are equipped with the skills, knowledge, and support they need to succeed in their roles and make valuable contributions to the organisation. The following are the key ingredients:

- Purpose and Importance: these talks provide key input for identifying training needs, discussing points for development, and addressing steps to promotion. The talks allow for open communication and constructive feedback between the staff and their supervisors, which is vital for maintaining a healthy work environment.
- Professional Approach: T&P strives to approach the R&D talks with professionalism. We ensure that all participants understand the purpose of the talks and what is expected of them. We aim to provide clear guidelines for conducting the talks and give staff the opportunity to prepare for the talks in advance.
- Assessor and Agenda: the R&D talks with academic staff are conducted by two assessors: the supervisor and the department (co-)chair. The department chair establishes the agenda for the talks based on HR's instructions and incorporates department-specific topics. The agenda typically includes topics related to leadership, personal mission, vision, and pathway to (societal and/or academic) impact, highlights and low points of the previous year, well-being and social safety, broader roles in the organisation, coaching roles, ambitions for the future, and development needs.
- Outcomes and Next Steps: based on the outcomes of the talk, we work together to identify training and coaching needs, explore new roles within the organisation, and consider potential steps toward promotion. In doing so, we aim to provide staff with the support they need to excel in their roles and advance their careers.

We value diversity in the impact of our academics and recognise the importance of fostering a range of career paths that result from this diversification. T&P has continued its appreciation of aspects other than scientific output and quality in the yearly R&D meetings, as well as in the monthly progress talks with supervisors and junior/mid-level staff. Attention is paid to personal well-being, group development, valorisation and societal impact, outreach, and networking in these talks. T&P has emphasised increasing collaboration between its academic staff members, e.g. via the new lab-based system and

the associated responsibilities. The fact that labs are generally coordinated by two lab directors increases further collaborative thinking, requiring the harmonisation of personal and group missions. Vision and strategy development as well as collaboration with the other labs are a central part of R&D talks with lab directors.

8.5 Evidence

A comprehensive set of indicators has been carefully selected to assess the outcomes of the chosen research strategy implemented over the past six years. These indicators have been split into three categories: “scientific quality,” “both quality and relevance,” and “societal relevance”. See Table 22 for an overview of the key indicators.

When evaluating scientific quality, we consider traditional metrics such as the number of papers published in top-tier scientific journals within our field or related areas, as well as the Scopus citations received by these publications. From these publications, we are interested in the number of joint publications between the Labs, as this is evidence of the ambition underlying our internal reorganisation to enhance collaboration. We also monitor the progress of PhD projects, ensuring their timely completion as an integral part of our strategic objectives. Moreover, we emphasise the utilisation of research outcomes, particularly by integrating our master’s and PhD candidates into the industry upon completing their research, as this aligns with our aim of increasing societal impact.

We believe that the excellence and peer recognition of the research conducted in mobility and transport can be gauged by several factors, including the number of personal grants received, involvement in editorial boards of transport journals, and participation in review panels for funding agencies to select projects for financial support.

In the realm between scientific quality and societal relevance, it is crucial to measure the number of pilot projects implemented within our research initiatives. These pilots bridge the gap between fundamental and applied research and are often conducted as part of European projects, which we also aim to expand to increase the impact of our research. We also strive to monitor progress made with regard to the inclusivity and diversity of staff members because of our implemented policies, using female-male ratio indicators since our strategy focused on increasing female representation in the T&P department.

Another important aspect to consider is the publication of open-access materials, including datasets, which serve to expand the accessibility and applicability of our research to practitioners and researchers worldwide. Additionally, the development and utilisation of decision-support tools in practical contexts serve as valuable indicators. In terms of societal relevance, this aspect is of paramount importance in assessing the evidence from the past six years, as our strategy is centred around increasing impact. To gauge the applicability of our research in a societal context and its potential to enhance mobility and transport, we measure the number of living labs incorporated within our projects. Furthermore, we evaluate the adoption of our methods directly by stakeholders through decision support tools. For instance, our case study on “low-car cities” provides insights into the production and utilisation of these tools, which support stakeholders in advancing sustainable mobility.

From a societal perspective, we examine the connections of our PhD candidates and staff with significant societal stakeholders, both in terms of funding and collaboration. This integration enables the direct inclusion of societal viewpoints in research projects, facilitating accelerated impact and change. We have also collected information on where our graduated PhD candidates continue their careers, thus assuring knowledge transfer.

The active involvement of our staff members in advisory boards and engagement with the media is particularly important, given the influential role of transport in people's daily lives. Our case study on "Mobility management during a pandemic crisis" exemplifies how the T&P department has effectively responded to urgent societal needs by developing and deploying critical methods and tools for decision support and policy making. Additionally, our engagement with authorities and participation in decision-making processes further contribute to our societal impact.

Table 22 Overview of evidence indicators.

	Scientific Quality	Both Quality and Relevance	Societal Relevance
Outcomes	**Peer-reviewed articles** in top journals in the field. **Joint interdisciplinary publications** in the field of transport and mobility. Multiple labs of the T&P department are involved in the publications. **Timely completion of PhD projects** with high scientific impact.	**Prototypes and pilots** of new solutions for planning and managing mobility and transport systems. **Diversity of PhD candidates and staff** involved in the research projects for enhancing outreach and impact.	Projects developed with **living labs** where citizens have a direct role in shaping research, thus improving and accelerating their impact.
Use	**Citation counts** based on the SCOPUS database, which demonstrate the usage of the research by peers. **Guest researchers** who visit our T&P department for part of their research.	**Tools and methods** produced to be used in a practical context by stakeholders. **Open-access** publications and open-access data sets.	**PhD students** who take jobs in the industry and continue in academia after they graduate. **PhD graduates and faculty** provide direct advice to practitioners and industry partners, and are occasionally funded by them. **Societal groups use methods and tools** developed in several projects to make decisions that improve key performance indicators.
Recognition	**Personal grants** awarded to members of the T&P department. **Participation in editorial boards** of top scientific journals in the field. Participation in juries and assessment committees of scientific proposals.	**Funded projects** by European funding agencies. Funded projects by NWO.	**Societal committees**, such as standards and government advisory boards, as well as selection and design award juries. Staff members' **media and outreach activities.**

8.6 Accomplishments during the past six years – research quality and societal relevance

8.6.1 Organisation and staff

The Labs that make up the department help expand knowledge and shape future research, as well as providing opportunities to hire young staff members with new expertise. The Artificial Intelligence for Mobility (AIM) Lab and the recently established Mobility in eXtended Reality (MXR) Lab have young, ambitious leaders. The new lab structure has fostered academic entrepreneurship, accountability, and leadership among younger staff. In the assessment period, the long-standing collaboration with the national road authority RWS resulted in structural funding for the appointment of two Academic Career trackers (Calvert, Sharif Azadeh), who work on "network management" in a

connected and automated world and “network planning”, respectively. Further, we have a joint appointment through the AMS research fellowship for Rinaldi and Venverloo. In total, T&P appointed seven Academic Career Track Assistant Professors from 2017 to 2022. Looking at the total number of faculty members employed at T&P in 2022, we have eight more faculty members than in 2017. The total Research FTEs have also increased since the last research assessment (see Appendix B.1). The increased growth of the department comes with some challenges that may require improvements in the future.

Internationalisation efforts led to greater diversity (40% of our faculty members are international) in cultural backgrounds through merit-based and open-call recruitment. Besides hiring from diverse backgrounds, we also have an average of 15 guest researchers per year at the T&P department. During the assessment period, we focused on improving the department’s gender balance, with four out of six new hires since 2020 being female colleagues. The share of females among faculty members has increased from 18% to 34%, even reaching 55% among Assistant Professors. While the overall female-to-male ratio among Assistant/Associate Professors is balanced at 47%-53%, achieving gender balance in senior positions remains a goal, as only one out of seven Full Professors is female (15%).

T&P’s strategy has resulted in a higher PhD yield with the percentage of PhD candidates completing their project within five years climbing to 60%, compared to 30% during the last research assessment period. PhD candidates have networking opportunities within the labs and through membership in professional organisations such as Connekt and the TU Delft Transport & Mobility Institute. After completing their PhD projects, some T&P graduates pursue an academic career, while others conduct research in the R&D teams of mobility consultancy firms and other companies in Europe such as Royal HaskoningDHV, Witteveen&Bos, Arcadis, Movares, Arup, Goudappel Coffeng, and SWECO.

Several T&P staff members have also obtained important, socially relevant positions. Hagenzieker, for instance, was appointed as a member of the steering committee of the CBR, while Van Arem became a member of the Klimaatraad. Recognition of our work is also evident through other awards and appointments, including Hoogendoorn’s KNAW appointment and Goverde’s presidency of the International Association of Railway Operations Research.

8.6.2 Scientific Quality

The department’s research output and quality achievements in the last assessment period are demonstrated by the increase in peer-reviewed journal articles, from 87 in 2017 to 122 in 2022, with an average of 116.5 articles per year, which is more than double the number of publications during the previous assessment period (averaging 53.5 articles per year). Furthermore, the average number of PhD theses per year has risen from 4.3 to 10. These numbers have allowed us to maintain and strengthen our position and recognition in the international research community. Moreover, distinguished awards have been received for multiple conference papers, representing about 3% of the total contributions during the assessment period. Notable achievements include Correia’s 4th place in the TRAVISIONS 2022 Senior Researcher competition in the cross-modality category and Besinovic’s 3rd place in the 2017 IEEE ITS Best Dissertation award.

T&P staff have expanded their contributions to steering research quality through their involvement in editorial boards, scientific boards, Transport Research Board (TRB) committees, and review panels for funding agencies. T&P has strengthened its representation in transport journals such as Transport Reviews, IEEE ITS Transactions, and Transport Research Part B, Part C, Part E, and Part F.

The Lab structure has increased internal collaboration, sparking unique projects that leverage the breadth and depth of our research. This is evidenced by Figure 23, showing how the collaborations between the labs resulted in joint publications in the assessment period.

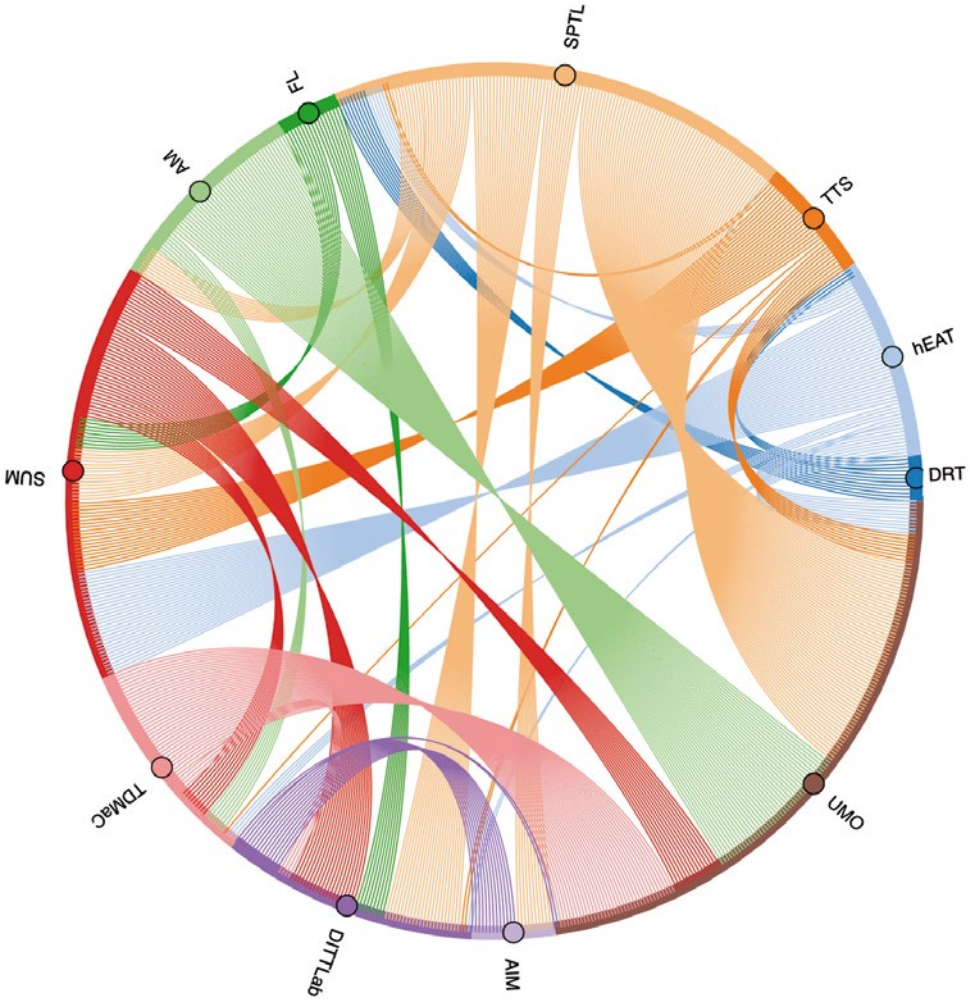


Figure 23 Connections between labs based on joint publications in the assessment period. Note that the AIM lab is new and has few joint publications yet with the other labs.

The department has successfully obtained several European grants, particularly from the EC and ERC. During the assessment period, grants from NWO and KNAW represented approximately 20% of the department's project income. The European projects accounted for a stable source of funding, including 18 EC Horizon projects (including one personal ERC grant) and two EC Interreg projects. These European projects amounted to 35% of the total grant funding obtained during the assessment period. The average yearly income from secondary and tertiary money streams was 3.98m€, representing an average funding increase of 60% compared to the previous assessment period. Moreover, the average funding acquired per year per research FTE from Assistant/Associate/Full Professors has doubled compared to the previous assessment period. Personal grants, such as CrowdIT (Veni grant) and CriticalMaaS (ERC starting grant), also highlight the department's accomplishments.

Several algorithms and tools have been developed in those projects. The AM Lab CityFlows project, for instance, focused on enhancing crowded pedestrian spaces through a unique crowd-management system that incorporates advanced monitoring techniques (theme A). The EU DIT4TraM project, led by Hoogendoorn, adopts a bottom-up approach to empower traffic participants and travellers to optimise flows through swarm intelligence,

control algorithms, and cooperative traffic management, tested in six pilots. Similarly, the DRT lab focused on enhancing railway system resilience by modelling railway systems as complex networks in projects such as the EU's MOVINGRAIL. These initiatives contribute to advancing efficient and resilient transport systems (theme B).

Moreover, new methods have been proposed in multiple projects. XCARCITY, a recent NWO project, will develop digital twins of Almere, Amsterdam, and Rotterdam, making it possible to test low-carbon and accessible urban scenarios and interventions (Theme A). To increase safety (Theme C), the TTS lab secured an NWO-funded project called SAMEN, led by Farah, which utilises advanced simulation models and real-world experiments to enhance autonomous vehicle capabilities and develop strategies for mixed environments with both automated and human-driven vehicles. A core new method that the T&P has been nurturing is the use of AI (Theme D). As a co-founder of the Delft CiTyAI Lab, T&P aims to deepen our understanding of how individuals experience and engage with cities. The RAILS H2020 project is an example of AI integration in the railway sector.

8.6.3 Societal Relevance and outreach

EU funding is often oriented toward impact and mostly built around a quadruple-helix approach, which sees academia, industry, people, and public authorities collaborate to produce results, outcomes, and impact. The growth in leading or participating in European projects has increased T&P's involvement in fostering societal impact. Naturally, the assessment period between 2017 and 2022 has been highly influenced by the renewed appreciation of the importance of well-being and health during and after the COVID-19 pandemic. During the outbreak, new research opportunities led to projects such as SamenSlimOpen, in which various research fields work together to gain a better understanding of how COVID-19 spreads indoors. Experiments in real-life settings were conducted to observe how people behave and this information was combined with mobility data to evaluate the effectiveness of different reopening measures. In the pilot on reopening education during COVID (see case study in Appendix A.3.2), T&P collaborated with various schools and universities to test new monitoring and flow management systems to identify and prevent high-risk interactions.

Moreover, the department actively collaborates with AMS, which accelerates the deployment and testing of solutions for transport problems, particularly those in Amsterdam. This occurs on a project basis, as well as via cross-institutional appointments (PI appointments of Hoogendoorn, Cats, Van Arem; AMS research fellowships for Rinaldi, Venverloo). A recent collaboration with NDW and the Transport & Mobility Institute was initiated to develop a joint data analytics platform. Regarding health and inclusiveness in mobility (Theme C), T&P has established a collaboration with KiM (Knowledge Institute for Mobility Policy) leading to two PhD projects. It should also be noted that Hoogendoorn and Cats are KiM fellows. In the e-Hubs and the Smart Hubs projects funded by Interreg NW and KIC (EIT), the hEAT lab has produced tools to be used by municipalities in Europe to design networks of shared mobility hubs that sustainably fulfil mobility needs. The tools are made available through a company that bought the developed software. Finally, T&P is collaborating with eighteen municipalities to create the Mobility Analytics as a Service toolset to facilitate working with data through the EMERALDS project led by Hoogendoorn.

As part of its strategy, T&P has produced more open datasets and software products during this assessment period, peaking at 12 datasets in 2022. The percentage of open-access articles also increased from 79% to 89%. The Urban Mobility Observatory (UMO), led by Daamen, is a unique archive of traffic, transport, and mobility data accessible to researchers, public authorities, and practitioners, and was made possible by a significant investment by NWO. T&P also had a significant media presence, with an average of 26 media appearances per year in which department faculty shared recent developments and discoveries with society.

8.7 Strategy for the next six years

The basis for our strategy for the coming six years stems from a detailed SWOT analysis of T&P research and the underlying organisation. The SWOT was based on input collected from the members of the T&P department, findings and reflections made by the T&P writing team, and input from external stakeholders from interviews organised by the SIF and the visit to UC Berkeley.

Table 23 SWOT analysis department T&P

	Strengths	Weaknesses
Internal view	1. Size - the largest research group in our field outside of mainland China. 2. A comprehensive research portfolio (e.g., including active modes, freight, shared mobility, AI & mobility). 3. Scientific excellence of academic staff, incl. leading experts in their respective fields with recognition among peers. 4. Track record of personal grants (Vernieuwingsimpuls, ERC) and Horizon Europe grants. 5. Diversity - of technical, professional, and cultural backgrounds, gender, and experience ('age distribution'). 6. Strong academic reputation. 7. Academic entrepreneurship, stimulated through the lab-based structure. 8. Strong international academic network and European collaborations. 9. Strategic collaborations with key (inter-)national stakeholders. 10. Well-connected to relevant academics across faculties. 11. Well-connected to applied research institutes/centres, e.g., AMS, TNO, Mobility Innovation Centre Delft (MICD; see https://micd.tudelftcampus.nl/), Rail Institute, Transport & Mobility Institute. 12. Excellent experimental facilities, including nationwide data collection initiatives (UMO).	1. Current organisational structure only partially translates to the faculty's organisational principles, which sometimes leads to issues in terms of representation within the Faculty, project management, HR and finances. 2. Requires efforts to ensure cross-lab 'solidarity' and gaining labs support for department-wide interests. 3. Uneven level of (project) management skills among lab directors. 4. Peer-pressure/internal competition ('crowded')/sense of community 5. Not all permanent staff is able to acquire sufficient rates of funding from 2nd and 3rd money to cover own finances. 6. Perceived workload of staff (presumably related to self-imposed high expectations). 7. Relatively limited research collaborations with other departments in the Faculty (albeit increasing – Gravitation proposal, several smaller projects). 8. Community engagement can be improved, despite efforts made during the assessment period.
	Opportunities	**Threats**
External view	1. Role of transport in the decarbonisation of modern societies puts extra focus on transport research departments in the next decades. Connections to (increasingly critical themes of) energy and resilience (climate-adaptation). 2. Planning environment in the Netherlands is supportive in testing pioneering ideas through transport pilots. 3. Emerging (AI, digital twins, IoT) technologies with promising applications in transport. 4. Our research area being impacted by other research domains - especially AI, data, and complexity science - offering new opportunities for collaboration and tapping into new resources (graduates, funding). 5. Increasing connections with universities in emerging economies and regions (such as India and Latin America). 6. Good connections to professionals (incl. alumni). 7. Improving intra-faculty ties (thanks to re-designed master programme – e.g., crossovers, and the CEG research strategy). Another example is the MUDE (Modelling Uncertainty and Data for Engineers), in which all departments work together. 8. Strengthening relationships with key local and regional governments looking to enhance cooperation with applied research in the domain of urban and mobility transitions.	1. Competitive position in recruiting and promoting talent (salaries, (family) relocation support, start-up package). 2. Difficulty of relocating for newcomers (e.g., housing availability, international students). 3. Limited number of applications from the Netherlands and Europe, growing dependence on new hires from other regions. 4. A (relative) reduction in secondary research funding available. 5. Decreasing possibilities for collaborations with and recruitment of researchers from countries with knowledge security issues.

Our strategy for the coming years is to maintain and strengthen our position as a world-leading group in transport research. The breadth and depth of our research offers a vibrant, engaging, and inspiring environment for scientific talent. T&P has seen considerable growth during the assessment period, which has contributed to its viability and improved its capacity to address challenges and opportunities related to emerging technologies and societal changes.

Two prime research areas for the coming years are sustainable multi-modal traffic management and climate-change adaptation in transport. We have recently recruited two young talents with the relevant expertise. Furthermore, our strategy includes initiating scientific projects that address policy ambitions for introducing low-car or car-free areas as well as attaining an overall reduction in mobility. We also anticipate intensifying our contributions in the coming years with regard to equality and inclusiveness in transport and welfare beyond economic growth at several of our labs (e.g. space consumption, public transport services). Future research programmes will increasingly account for risk and uncertainty, the interactions between different sub-networks (e.g. infrastructures, services, power grid, information) and different kinds of flows (e.g. energy, goods, people) in planning, operations and control of multi-modal transport systems while considering the reduction of system externalities, e.g. by means of novel design solutions and demand management schemes. In doing so, we will capitalise on our strengths and opportunities for collaboration with applied research institutes, our excellent experimental facilities, the supportive planning environment for pilots, and our connections with relevant academics from related disciplines.

Our funding acquisition efforts will increasingly involve collaborating with partners from other disciplines such as energy, AI, complexity science, social sciences, partners from more diverse geographies and engaging in co-creation with local and regional governance organisations. Our strategy is to maintain a robust research funding portfolio consisting of personal (NWO, ERC) and consortium-based national and international grants (Horizon Europe, ERA-NET, OTP). In particular, multi-disciplinary research programmes and research innovation actions are expected to gain in importance, as are long-term partnerships with key regional players (e.g. City of Rotterdam, The Hague-Rotterdam Metropolitan Area, AMS), examples of which include the NWO XCARCITY and SUM projects, as well as other pending proposals. Inspired by our visit to the University of California, Berkeley, we will also invest in strengthening our ties with social partners to increase community engagement. This can be partly achieved via T&P's connection to the Transport & Mobility Institute (directed by Hoogendoorn).

8.7.1 Organisational structure

T&P will re-assess its organisational structure in light of its growth, while preserving the merits of our lab structure and stimulating their further development. This process is intended to address several of the weaknesses mentioned in the abovementioned SWOT analysis (Table 23, item 1. also 2.- 4.). In developing the adapted organisational model, special attention will be paid to facilitating academic leadership and cross-theme collaborations, ensuring the alignment of responsibilities and accountability, as well as improving information flow, the distribution of managerial tasks, span of control, and representation in the MT. We anticipate the introduction of sections, while continuing to stimulate the existing lab structure. The latter has proven successful in supporting the autonomy of young scientific staff, promoting academic entrepreneurship, developing a clear identity towards external stakeholders, and offering opportunities for exchanging information.

8.7.2 Open science

T&P is committed to open-science practices. Our strategy for the coming years is to involve stakeholders in developing research programmes based on our strategy and prevailing research needs, including by means of ideation workshops with lab partners, supporting the continuation of the SIF initiative. Our experimental data facilities are designed to maximise the reuse of data where possible, and researchers (from graduation projects to large research programmes) are required to make data, code and methods publicly available using FAIR principles, with publication being preferred. Our PhD guidelines explicitly highlight such contributions (i.e. the publication of open datasets and open software in public repositories). Special attention will be paid to the quality control of data management plans and collaboration agreements (incl. Knowledge Security considerations).

8.7.3 PhD Policy and Training

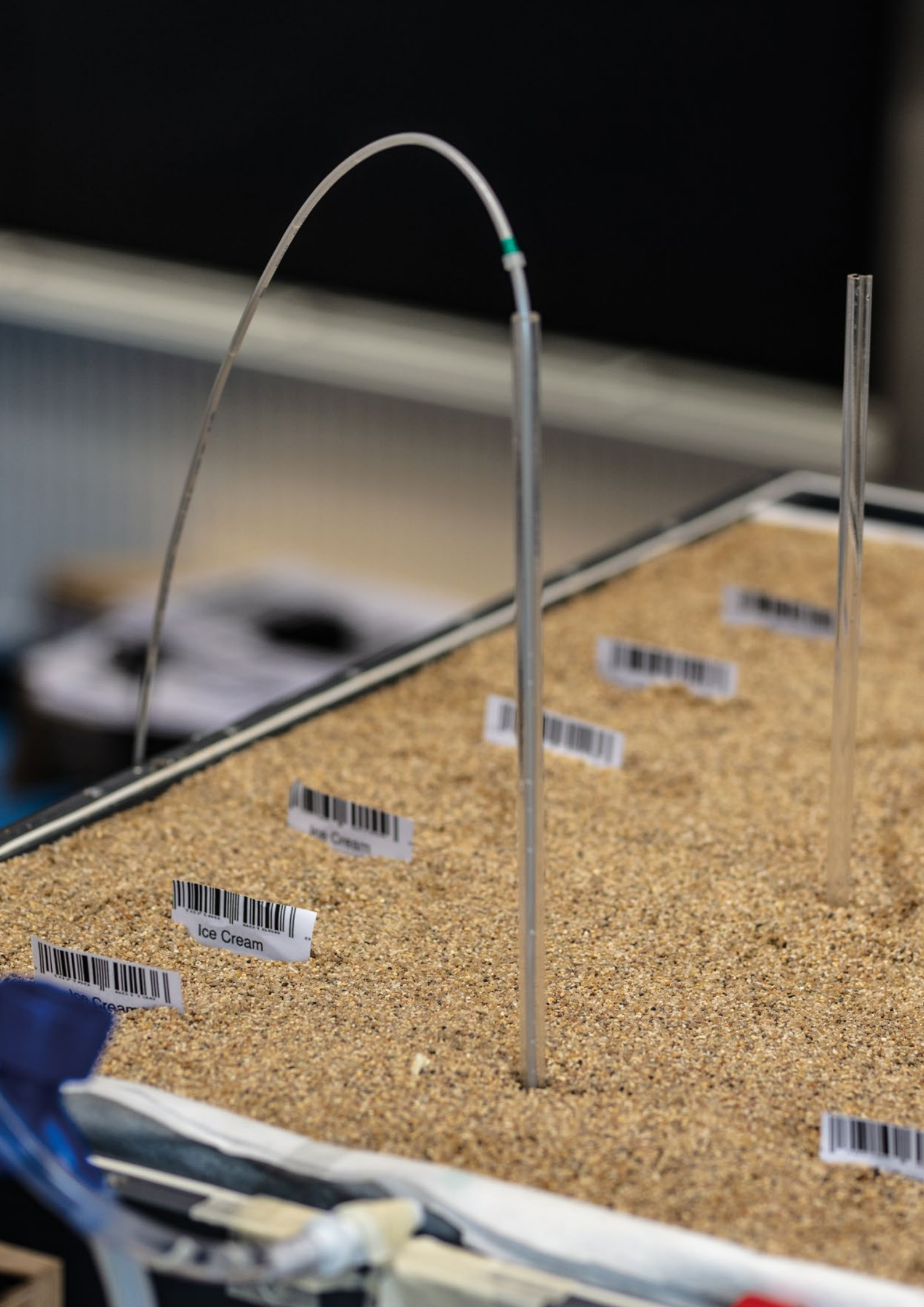
Our PhD policy and training strategy for the coming years stresses quality assurance in recruitment, training and coaching. For the former, we will capitalise on the department's newly established guidelines for paper-based PhD theses. We plan to create an 'onboarding package' for new PhD candidates, reinforce the buddy-system and establish clear guidelines for expectations and the go/no-go procedure. Furthermore, we are committed to ensuring a smooth, transparent, and inclusive process for selecting and admitting PhD candidates. To achieve this goal, we will encourage staff members to exchange best recruitment and selection practices. New staff members and their managers will frequently discuss supervision and coaching skills, as well as identifying and addressing training needs. Our aim is to attract and select the best and most diverse pool of applicants, and to provide them with the resources and opportunities they need to thrive and succeed in their academic pursuits.

8.7.4 Academic culture

In terms of academic culture**,** our strategy is to be firmly focused on the impact we are committed to creating and offering a merit-based, value-based, empathic and inclusive, and intellectually stimulating work environment. In the coming period, we intend to focus on improving the alignment of responsibility and accountability and the distribution of management tasks and responsibilities, including the mentoring of new members. This is expected to provide more opportunities for academic leadership, improve internal communication and solidarity, and contribute to well-being of employees in the T&P department. The latter is an important focus of the department, and we are currently making a deliberate effort to better understand and monitor employee well-being and we intend to introduce several measures, including reduced faculty service roles for new staff members and a more distributed management structure. We also intend to encourage non-native staff members to become proficient in Dutch to enhance their position in the Dutch academic and professional community.

8.7.5 Human resource policy

In relation to T&P human resources policy, our recruitment policy will follow our newly established process for the scoping of new positions where alignment with department strategy is key. The new Recognition and Rewards (Erkennen en Waarderen) programme policy provides excellent opportunities for performing a holistic assessment of staff members, including their contributions to team efforts, offering development opportunities for different career paths and (research and teaching) profiles, and connecting the R&D cycle to the academic leadership career track. The new departmental organisation will also embed the role of co-assessors in the R&D cycle. Our commitment to diversity is an important part of our identity and is therefore also key in selecting new staff members. Resonating with the insights gained from our visit to Berkeley, an inclusiveness and diversity statement will become an integral part of the material requested from job applicants.


Ice Cream

9. Department of Water Management

9.1 Introduction

The Water Management (WM) department is at the forefront of addressing water-related challenges and developing innovative solutions. The department consists of two sections, Water Resources and Sanitary Engineering, with, as of 2022, a total of 29 Assistant, Associate and Full Professors (Appendix B.1). Furthermore, WM has 16 researchers (mostly postdocs) and 137 PhD candidates, as well as nine support staff (secretariat, lab). The core expertise of the Water Resources section covers the entire terrestrial water cycle and includes major aspects of hydrology and water resources (e.g. hydrometeorology, catchment hydrology, geohydrology, urban hydrology, socio-hydrology, water system optimization and control, water law). Expertise in the Sanitary Engineering section covers disciplines related to wastewater treatment, industry water, drinking water, and urban water infrastructure. Expertise on water quality in the aquatic environment is spread across both sections.

Table 24 Societally relevant research themes within WM: scope, SDGs (United Nations' Sustainable Development Goals[29]) and examples of research topics for each theme.

Themes	Scope	UN Sustainable Development Goals	Research topics (examples)
Water and Energy in Urbanising Deltas	Water and energy sustainability in cities and urbanising deltas	SDG 6 - Clean water and sanitation SDG 7 - Affordable and Clean Energy SDG 11 - Sustainable Cities & Communities	Urban heat island, automated sewer inspection, AI and real-time control for managing urban water infrastructure and polders, sustainable urban drainage systems, non-sewered sanitation, water conservation and reuse, water-energy nexus, nutrient and energy recovery from (waste) water, aquifer thermal energy storage
Water, Health, and Disaster Preparedness	Managing water-related risks to protect human health and the environment	SDG 6 – Clean water and sanitation SDG 13 – Climate Action	Removal of (emerging) contaminants, groundwater quality, water pollution in river basins, cybersecurity of water infrastructure, early warning systems (wastewater surveillance, floods, landslides)
Water, Food, and Climate	Sustainable land and water management in a changing climate	SDG 2 - Zero Hunger SDG 13 - Climate Action	Hydrometeorological observations, climate services, land-atmosphere interactions, floods and droughts, (geo)hydrological modelling and management, smart irrigation, managed aquifer recharge, socio-hydrology

One of the unique strengths of WM is the wide range of water-related expertise within a single department, which allows us to tackle global water challenges related to water quantity (floods and droughts), water quality (pollution, treatment, and reuse), and water infrastructure, which necessarily cross disciplines. As such, research within WM is organised around three societally relevant research themes (Table 24) that involve collaboration between both WM sections, with a balanced research portfolio (projects, staff) among the themes. The relationship between the two WM sections and the department's research themes will be further elaborated below (see Figure 26, section 9.4.1)

9.1.1 Water and Energy in Urbanising Deltas

Within this theme, WM contributes to water and energy sustainability in cities and urbanising deltas. Research focuses on water reuse via treatment, and on operation and integrated planning of existing and new urban water infrastructure (water supply, sewers, nature-based urban drainage systems) in the face of climate change and urbanisation. WM also develops water-related solutions for the energy transition based on nutrient and energy recovery from (waste)water, aquifer thermal energy storage, sustainable heat grids, and smart operation of energy-intensive pumping in low-lying polder areas.

9.1.2 Water, Health and Disaster Preparedness

This theme focuses on protecting human health and the environment by reducing and managing risks associated with water pollution, landslides, floods, and failures in water infrastructure. WM develops new technologies for detecting and removing water contaminants in drinking water, sewage and groundwater, and works with stakeholders to measure and manage water pollution in river basins. WM research on forecasting water-related hazards, such as (flash) floods and landslides, and on early detection of cyber-attacks on urban water infrastructure, is used to develop early-warning systems.

9.1.3 Water, Food and Climate

Research in this theme contributes to sustainable land and water resources management in the face of climate change. WM develops novel techniques for measuring and modelling hydrological processes, such as rainfall, evaporation, runoff, streamflow, and groundwater flow. These tools contribute to a better quantitative description of the hydrological cycle, facilitate flood and drought management in river basins, and support sustainable agriculture, e.g. by providing climate services that help farmers better anticipate droughts during the crop growing season.

Besides thematic and disciplinary cross-over, WM is united by common research methods (e.g. AI, real-time control), joint educational activities (i.e. MSc Environmental Engineering programme) and shared facilities. Examples of the latter are the shared equipment for (hydrological) field work and the shared WaterLab (Figure 24). WM's WaterLab is a 500 m^2 laboratory space for experimental research and education, harbouring high-end analytical equipment, experimental set-ups, and generic research areas. The field instrumentation and WaterLab are available to all WM staff and students, meaning that strategic choices are made collectively. This team approach is illustrative for the working environment in the department, where a sense of shared responsibility allows for everyone to participate. The same approach was followed to prepare this chapter: it was based on input from all WM staff during two departmental strategy meetings, with a writing team of three staff members and an internal review team of four staff members. Additional insights from an international work visit to KU Leuven and Ghent University in Belgium are included in section 9.7. In this chapter, the terms "WM," "the department," and "we" all refer to the Water Management department and its staff.

Figure 24 Shared facilities at WM: (A) equipment for (hydrological) field work and (B) WaterLab, a 500 m² laboratory space with high-end analytical equipment for experimental research and education.

9.2 Mission and strategic aims during the past six years

Our mission is to advance fundamental scientific knowledge and to develop innovative engineering technologies and water management solutions to address key societal challenges related to water systems and their interactions with humans. We organise our efforts around the three societally driven research themes described in the previous section (Table 24) and thereby directly contribute to multiple SDGs, including water-related challenges in low- and middle-income countries in the Global South, where the need for solutions is most pressing. The function of these themes is to stimulate cross-disciplinary collaboration in the department, as well as guide towards a shared longer-term vision. As such, the themes can aid in strategic choices in the department (e.g. new hires, joint project proposals). To implement our thematically structured mission, we pursue four strategic aims (Figure 25).

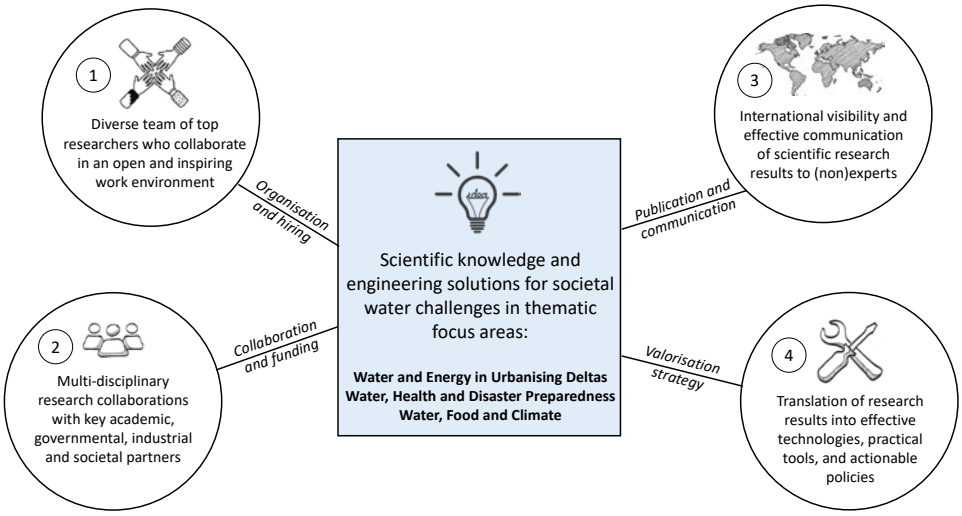


Figure 25 Central mission of WM implemented via four strategic aims with corresponding strategies to create scientific and societal impact and ensure viability.

The first strategic aim is to maintain a diverse team of top academic staff that collectively cover the broad range of domain-specific expertise required to tackle today's complex water management problems. This includes proactively strengthening water expertise within the department, e.g. on biological water treatment, groundwater quality, and new tools such as AI. We pursue a high level of scientific excellence and a collaborative environment of transparency, inclusiveness, and diversity. As such, an important aim during the last six years was to further integrate the Water Resources and Sanitary sections in the department. Increasing diversity in gender, age, cultural background, and experience of staff is also important because it results in resilient and adaptive teams that innovate in unexpected ways.

A strong internal team, however, is not enough: collaboration with external partners and stakeholders is key for making real impact. For this reason, WM has developed strong ties with water authorities and companies in the Netherlands and maintains a significant international collaborative footprint. Maintaining and strengthening these existing collaborative research networks with governmental agencies, companies, research institutes, and other universities is our second overarching strategic aim (Figure 25). Since this second aim aligns with typical co-funding and consortium requirements of funding agencies, it also contributes to the financial viability of the department.

Our third strategic aim relates to creating impact through scientific publications and communication of research outputs to wider societal stakeholders. In all three cross-disciplinary research themes, we aim to make our research output widely available to an international audience of scientific peers using a publication strategy rooted in open science. Embracing our disciplinary diversity and collaborations, we publish not only in internationally leading discipline-specific science and engineering journals, but also in more broadly scoped journals, such as the Nature family of journals for our research of global scope. Communication of research results to non-experts and the public is pursued via press releases, media appearances, presentations and activities for school children and non-scientists, the use of social media, as well as open-source educational activities.

Our fourth strategic aim is to generate societal impact by translating research results into effective technologies (e.g. novel water treatment), practical tools such as software and data (e.g. climate services from novel precipitation sensors), and actionable policies (e.g. developing strategies for dealing with floods and droughts). Our aim is to do this together with societal partners.

Our mission and strategic aims allow us to make fundamental contributions to the five faculty-level research themes, i.e. the availability of clean water, climate change, transition to renewable energy systems, resource depletion, and urbanisation. Research at WM also aligns well with national programmes such as the Top Sector Water and the Dutch Research Agenda (NWA), particularly the NWA 'routes' or themes on water ('Blue route'), circular economy, energy transition, smart and liveable cities, big data, and global development ('NWA-SDG' led by WM; van de Giesen).

9.3 Follow-up from previous assessments

This section briefly addresses the most pertinent recommendations made during the previous research assessment and the mid-term assessment.

9.3.1 Demonstrating impact

The midterm assessment report mentioned that *"the societal relevance can be demonstrated much more clearly"*, "*the impact of the research is not systematically measured"*, and "*the outreach to the Southern Hemisphere deserves better visibility*". We have assembled multiple indicators and concrete examples to systematically measure and demonstrate the scientific and societal impact of our work: see section 9.6 and case studies in the Appendix A.4 (one of which emphasises the Global South).

9.3.2 Strengthening research fields

The midterm committee noted that *"the impact of WM can grow even further in the research field of water and food, anaerobic treatment and circular thinking.*" In section 9.6 we document the growth in all these areas, which has resulted in further consolidation of our excellence in these research fields. In the 2018 review, it was noted that "*further focus could be given to strengthen groundwater research.*" Since then, groundwater expertise within WM has been extended with new staff members (see section 9.4), and several groundwater-focused research projects have been funded (see section 9.6).

9.3.3 Academic Career track start-up package

The review committee mentioned that *"the tenure track system at Delft has been well taken up in the Water Management department"*, but "*There is significant room for improved start-up packages."* (Review 2018). Across the Faculty, the start-up package has increased from 50k€ per Academic Career tracker (for personal development) to a grant for a full 4-year PhD candidate (210k€ in salary costs) since 2019. See also section 9.4.

9.3.4 WM department taken for granted?

A critical remark made by the review committee in 2018 was that *"A programme such as WM that has a long history of success, may gradually be taken for granted […] and loose support. This should be avoided at all costs".* We agree that this is a potential risk and believe that it can be effectively tackled by continued innovation combined with (more) effective communication of our work and its impact. In section 9.6 we provide concrete examples of how we have done this, with further reflection on how to improve visibility through a targeted communication strategy in section 9.7. The review committee further remarked that "*it is important for WM to be clearly visible to students in the Faculty. Earlier introduction of students to topics in WM in the degree programs would help.*" This remark alludes to the relatively limited number of water courses currently offered in the BSc Civil Engineering curriculum. We acknowledge this concern and have taken proactive measures. WM is currently actively involved in a Faculty level committee, with the specific goal of increasing visibility of WM and of the new Environmental Engineering MSc programme to BSc students. The next few years will show the effectiveness of our efforts to increase our visibility.

9.3.5 A balanced project portfolio

The midterm assessment report noted that *"the funding strategy involves many consultancy projects, but always with a longer-term goal. This seems unsecure, compared to longer projects and may be a risk at the longer term"*. We believe this remark stems from confusion about the term "contract research" used as funding category (3rd money stream) in the previous midterm report: this does not refer to consultancy but consists primarily of research projects that are funded by other means than NWO (2nd money stream), including funding from EU projects (e.g. Interreg, Horizon), the Dutch government (e.g. RVO/TKI), industry and private donors. We believe the project funding portfolio of WM department is diverse and well balanced. Nevertheless, we are aware that funding landscapes change, and we regularly re-evaluate our project portfolio.

9.4 Strategic process of the past six years

This section describes our strategies (corresponding to the edges in Figure 25) and highlights early outcomes of strategic choices (e.g. in hiring or organisation) that occurred the past six years. These choices and outcomes form the basis for WM's scientific and societal impact discussed in section 9.6.

9.4.1 Organisation and hiring strategy

Strategic organisation for greater synergy and individual excellence

A deliberate decision was made to adopt a more collaborative and integrated approach inspired by the key societal challenges defined at the Faculty level and the associated SDGs. The department moved away from the traditional organisational structure of professor chairs, where a single (senior) PI would lead the team, towards a team-player PI model (team-PI model). This is a flexible model for research (and education) teams with a strong informal component, where staff are encouraged to organise themselves to collaborate in flexible configurations on research topics within the three major WM themes[39]. Such an approach benefits from the advantages of a flat hierarchy centred around individual excellence, while leveraging the significant multi-disciplinary expertise within the department, which we see as a unique strength of our group. From a viability perspective, this new structure is believed to be more inclusive and sustainable. Figure 26 illustrates how this team-PI model enables theme-driven collaboration across the two sections (Water Resources and Sanitary Engineering) within the department, with shared management (MT=Management Team, and EduTeam=Educational Team) and shared experimental facilities (WaterLab and shared instrumentation). Table 36 in Appendix C.3 provides a selection of team-PI projects to illustrate our cross-disciplinary collaboration in each theme.

Recently, the key role of individual PIs within this model has been boosted by increasing the start-up package for newly hired Assistant Professors. In 2019, this package was increased across the entire Faculty from 50k€ (for personal development) to a grant to support a full 4year PhD candidate (210k€ in salary costs). We have seen that this allows for our new, often junior, staff to get settled faster in the department, which is important, as more Assistant Professors are currently being recruited. To keep this growing group connected, we have increasingly merged both informal (group outings, end-of-year dinner) and formal (department meetings, colloquia) events across the historical division of the two sections (Water Resources and Sanitary Engineering). This has increased collaboration between WM staff, both in education (MSc Environmental Engineering) and research. The team-PI model not only fosters collaboration but also stimulates individual excellence, as illustrated by individual grants awarded to team members, as well as the high number of publications in scientific journals by WM individuals (see section 9.6).

[39] The department follows the faculty wide Department Organisational Principles (DOP); department budgets, financial reserves and hiring strategy is organised at department level.

Strategic hiring for greater diversity and stronger positioning

In the period 2017-2022, the department had a rather stable number of scientific staff, with a slight increase in the number of Associate Professors (from 2.3 to 4.2 FTE). To improve the quality of our laboratory, particularly in developing analytical methods, we have extended our overall support staff from 2.9 to 6.9 FTE (see Appendix B.1). The department pursued an active strategy of increasing the proportion of female academic staff (strategic aim 1). In 2017, the seven females in the department were either Assistant (5) or Associate Professors (2). Six years later, the department is home to one female Assistant Professor, three female Associate Professors and three female Full Professors, one of whom moved to another CEG department). This was achieved by hiring new female staff (Blokker, Rutten, Lompe), as well as promotions to Associate Professor (ten Veldhuis) and Full Professors (van Halem, Steele-Dunne, de Kreuk). This increase in seniority and visibility of female professors in the department is gradually changing the work atmosphere to a more inclusive environment for both staff and students. We also note that the appointment of de Kreuk in 2022 as Department Chair was an historical first, as she is the first female Full Professor to serve as Department Chair in the Faculty (i.e. first female Full Professor in the CEG Faculty MT). Nevertheless, an overall increase of female scientific staff has not yet been achieved in the period 2017-2022. The diversity of WM scientific staff, however, did increase: the percentage of non-Dutch Assistant Professors rose from 23% in 2017 to 62% in 2022. New PhD candidates between 2017 and 2022 were 46% female and 83% non-Dutch. Our department is more broadly committed to diversity, as well as being actively represented in the Faculty Diversity and Inclusion (D&I) team, which aims to strengthen and support the Faculty's D&I policies.

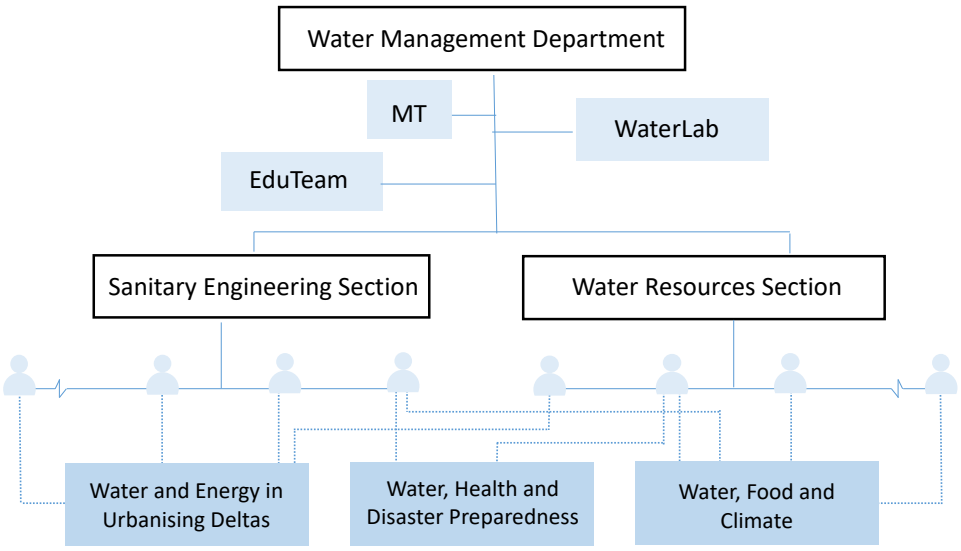


Figure 26 Organisational structure of the WM department with the team-PI model bringing together PIs from both sections to collaborate on one or more of the departmental research themes. Each PI is typically involved in 1-2 themes. MT=Management Team and EduTeam=Educational Team

Groundwater expertise within WM was expanded. First, a new Academic Career Track Assistant Professor on renewable (shallow geothermal) energy systems was hired in 2020 (Bloemendal; 0.6 FTE until 2022, currently 0.8 FTE). Second, Foppen (Associate Professor pathogen transport in groundwater) from the IHE Delft Institute of Water Education has been associated with WM (0.2 FTE) since 2020, before becoming a full-time employee in 2023. In addition, van Breukelen, an expert on chemical hydrogeology, was tenured as Associate Professor in WM. Finally, as of August 2023, Störiko will join our department as Assistant Professor of Environmental Water Quality with a focus on groundwater.

Other strategic hires were aimed at strengthening and broadening existing expertise in the department. These include Kapelan (urban drainage and drinking water distribution systems), Uijlenhoet (hydrometeorology), Mehta (computational fluid dynamics), Rutten (integrated water management), Lompe (emerging contaminants), Blokker (water distribution), Taormina (cybersecurity, AI, and water management), van der Ent (atmospheric water cycle), Laureni (biological wastewater treatment), and Droste (urban hydrometeorology).

9.4.2 Publication and communication strategy: open science and outreach for greater impact

WM strongly shares the "as FAIR as possible" principles and promotes open science. As shown in Table 2 in chapter 4 on Open Science, the percentage of open-access scientific publications by the department has grown rapidly from 59% in 2017 to 99% in 2022. Besides the high level of sharing of open publications, the "Water Community for Impact'' initiative and its website[40] are good examples of the department's commitment to open science, with the website serving as a portal for research that addresses worldwide water challenges along our thematic areas of research. Many recent research outputs (scientific publications, MSc and PhD theses) and ongoing projects are shared for open and easy access by scientific and social actors. Another example is the eWaterCycle project led by WM PIs, which mainstreams "FAIR Hydrological Models" through its platform for making and sharing open hydrological models and data for full reproducibility.

WM is also actively promoting data sharing through the projects and initiatives it leads. The TAHMO initiative openly shares its weather data with researchers, government agencies, and other stakeholders to improve water management and climate adaptation in Africa. Multiple projects by WM staff employ citizen science approaches, for example by contributing to SmartPhones4Water[41] where citizen-collected data are available for research and the wider community. Since 2020, WM has played a leading role in "Delft Measures Rain" (now "Delft Measures"), involving the citizens of Delft in collecting data on urban rainfall and climate[42]. WM also takes part in the 4TU Plantenna initiative, where ten Veldhuis and Uijlenhoet spearhead contributions from WM on open sharing of innovative sensor technology on plant conditions and the environment.

We also note the vital role open education plays in sharing research. The WM department was the first to introduce a MOOC at TU Delft and now leads four MOOCs on drinking water, sewage treatment, water & climate, and the energy transition. Van Halem received the ES Open Education Ambassador Award for her role in the MOOC on drinking water treatment. More recently, Bloemendal kicked off a MOOC on the decarbonisation of heating, garnering cross-faculty collaborations. Staff is also involved in online professional education (ProfEd courses on membranes and aerobic granular sludge, each with 30-60 students twice per year, and anaerobic treatment starting in 2023).

Regarding communication and visibility, in 2021 we established the Water for Impact programme as part of the campus-wide Delft Global Initiative, which has increased the visibility of our international research agenda and activities in Africa in particular (see also case study in Appendix A.4.2). The programme has an active community on LinkedIn (>3,000 followers), organises events (e.g. Water Summit for Global Development 2022 and official side-sessions at UN Water Conference 2023 in New York), maintains the interactive watercommunity.nl website, and initiates cross-department research projects (e.g. the African Water Corridor in Ghana, Mozambique and Uganda). Finally, in section 9.7 we report on more recent developments in our communication strategy, namely the formation of a dedicated WM communications team for more directed and systematic outward communications.

[40] https://www.watercommunity.nl
[41] https://smartphones4water.org/data
[42] https://www.tudelft.nl/scd/waterlab/doe-mee-aan-onderzoek/project-7-delft-meet

9.4.3 Collaboration, funding, and valorisation strategy

WM's strategy involves maintaining a balanced funding portfolio of personal grants, basic research projects funded by NWO and the EU, collaborative ventures with industry (e.g. TKI), and co-funding schemes to tackle water-related issues at local and regional levels. The scope of our work ranges from addressing typical Dutch water problems to the intricate challenges related to water access in the Global South. To maximise the societal impact and valorisation of our research, we actively engage with societal partners. An important development during the past six years was the implementation of the Engineering Doctorate (EngD; formerly PDEng). In this 2-year project, the candidate works on a specific engineering or design problem with an industry partner. Recent EngDs, for example, have worked on dune water treatment (with Dunea) and water reuse for concrete manufacturing. Such projects are excellent opportunities to engage in more science-oriented research projects (typically PhD candidate or postdoc projects) and applied impact-driven projects with industry or societal partners.

We firmly believe in collaboration with societal partners and our strategy is to maintain strong expertise in social aspects, including socio-hydrology (Pande), water law (Mostert), resource recovery and society (Palmeros Parada), and stakeholder engagement (Rutten). We are also actively involved in inter-disciplinary initiatives on campus (e.g. The Green Village, the Climate Action programme, Flood Proof Holland), and we collaborate with research groups in other related research fields such as Environmental Biotechnology (Faculty of Applied Sciences). We work together on joint projects on water treatment (e.g. NWO RedOx Filter) and joint supervision of PhD candidates. Collaborations with the Faculty of Technology, Policy and Management (TPM) and the Faculty of Industrial Design Engineering (IDE) are also noteworthy, particularly when working at the intersection of water solutions and human behaviour or societal dynamics. Examples include the H2O2 Pavitra Ganga project with Scholten (TPM), NWO DELTAP with Karana/Diehl (IDE), AGRICOAST with Minkman (TPM), and 4TU HERITAGE with Van Esch (ABE). Further examples are provided in section 9.6. We are also involved in an off-campus collaboration with IHE Delft: an MoU has been established, and all PhD candidates at IHE who defend their theses at TU Delft are supervised by a (co-)promotor from TU Delft.

9.5 Evidence

This section provides an overview and explanation of the indicators (Table 25) and case studies that were selected to measure and assess, in section 9.6, WM's scientific quality and societal relevance.

Table 25 Selected indicators of scientific quality and societal relevance.

	Scientific quality	Both quality and relevance	Societal relevance
Outcomes	Peer-reviewed publications (including open source)	New technologies Open-source data and software	Contribution to SDGs Public outreach and education
Use	Scopus citations	PlumX Metrics	Application of WM knowledge, tools, and technologies
Recognition	Personal grants and awards Academic collaboration and network	Funded collaborative projects	Projects with societal and industry partners

We use peer-reviewed scientific publications in Scopus as the main indicator of scientific output. Together with Scopus citations and PlumX Metrics, these indicators measure whether we attained our goal of international visibility and effective communication of research results to peers (strategic aim 3 in Figure 25). Additionally, personal grants and awards are used to indicate the scientific excellence of WM staff (strategic aim 1). Indicators and achievements of diversity in WM (e.g. number of female and non-Dutch staff), which is also important for strategic aim 1, are addressed under paragraph "Strategic hiring" in section 9.4 and section 9.7.

The team-PI model promotes collaboration within WM (strategic aim 1). Table 36 in Appendix C.2 provides examples of collaborative projects that were spawned following the adoption of the team-PI model. The model also allows us to share our partners, resources, and expertise, and as such stimulates multi-disciplinarity. Multi-disciplinary research collaboration (strategic aim 2) is assessed using the following indicators: (i) the international collaborative footprint of WM, i.e. the worldwide geographic distribution of co-authors of peer-reviewed articles, (ii) funded collaborative projects, and (iii) projects with societal and industry partners.

Societal relevance is evaluated by the extent to which research at WM contributes to the SDGs, and by the communication of research results to non-experts via MOOCs and public outreach (strategic aim 3). Attainment of strategic aim 4, which is to create societal impact by translating research results into effective technologies, practical tools, and actionable policies, is evaluated by documenting examples of each, including e.g. pilot-scale testing of novel water treatment technology, the development and application of novel sensors and simulation models, and the adoption of water management plans and operational strategies based on research at WM.

In addition to these indicators, we use two case studies to demonstrate impact. The first case study, "Circularity in the urban water cycle", highlights how close collaboration with societal and industry partners accelerates new technology adoption in the water sector and allows WM to translate fundamental research that advances scientific understanding into technological solutions that address societal challenges. The second case study, "Rainfall mapping in Sub-Saharan Africa", showcases WM's significant contributions to water-related SDGs via its research activities in the Global South.

9.6 Accomplishments during the past six years – research quality and societal relevance

In this section, we describe our accomplishments in terms of the indicators in Table 25 and reflect on our overall achievements (scientific and societal), as well as the achievements per WM overarching research theme as defined in our mission.

9.6.1 Overview: scientific quality and societal relevance

Water management has been an established research field at TU Delft for more than 75 years, with a long history of research with the Dutch water sector and a strong international reputation (e.g. in ARWU/Shanghai Subject Rankings, TU Delft Water Resources is consistently ranked in the Top 10). With the indicators in this paragraph, we intend to illustrate that WM's research is still growing today, both in quality and (international) reach. We note that publication-based data reported here include output from both core WM staff (see Appendix B.1) and staff affiliated with WM (e.g. IHE-Delft professors).

The scientific quality of WM is illustrated by the increasing number of peer-reviewed publications during the last six years, with on average 214 peer-reviewed journal articles per year compared to an average of 155 per year for the previous assessment period

2011-2016 (Figure 27A). It is noteworthy that this rising number of publications was achieved with a relatively stable number of PhD theses (Figure 27A). Many of these publications are in internationally leading disciplinary scientific journals (Water Research, Hydrology and Earth System Sciences (HESS), and Water Resources Research), and most are open access (see section 9.4). Use of this research output by peers is shown by the number of citations of our published work. Together, WM's publications over the period 2017-2022 have so far been cited more than 20,000 times (based on Scopus, Figure 27B). Publications span across WM disciplines and themes, illustrated by a few highly cited publications from 2017-2022: "High-silica zeolites for adsorption of organic micro-pollutants" (Water Research, 278 citations since 2018), "Organic Pollution of Rivers" (Scientific Reports, 178 citations since 2017), and "Twenty-three unsolved problems in hydrology (UPH)–a community perspective" (Hydrological Sciences Journal, 379 citations since 2018).

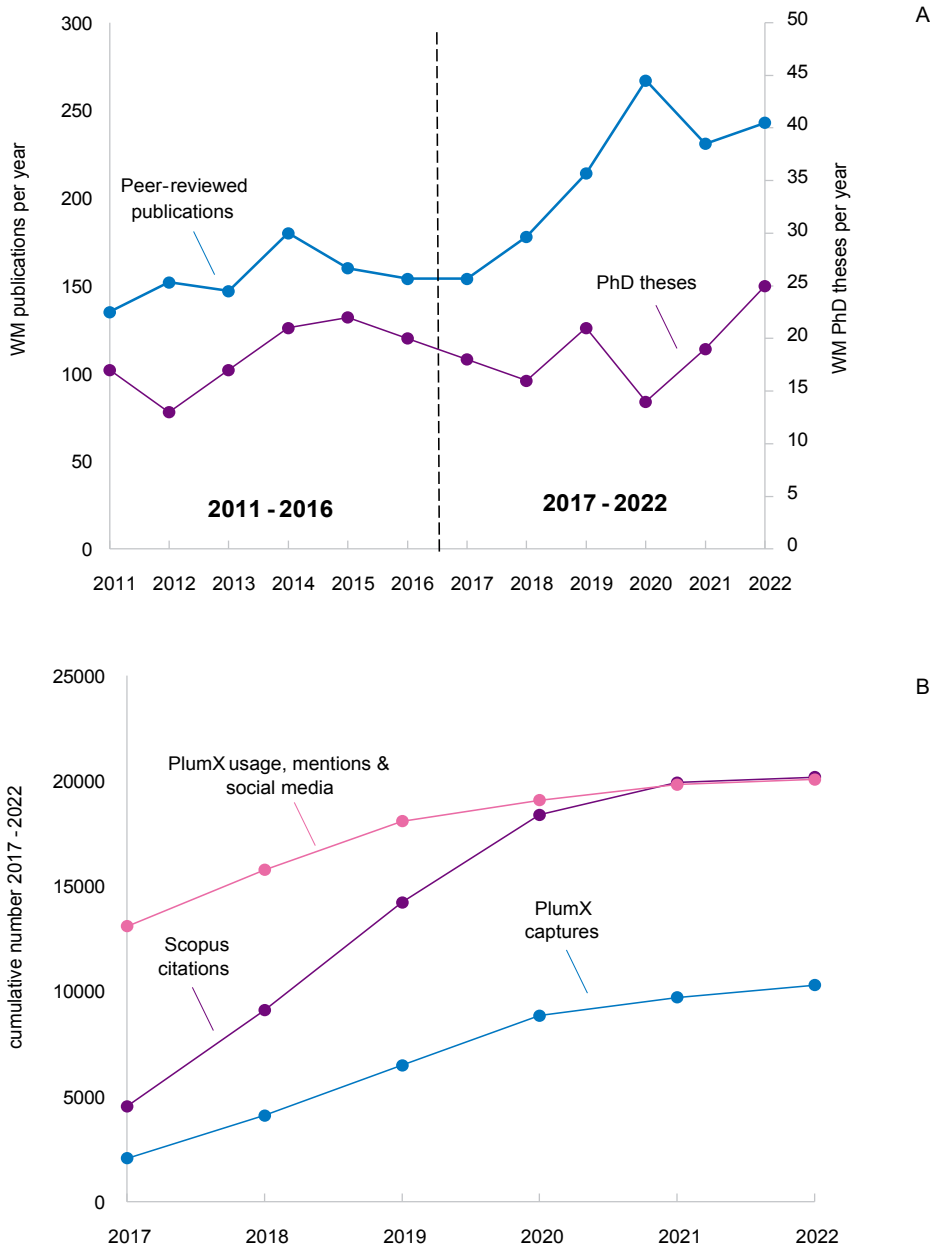


Figure 27 A) WM publications and PhD theses per year from 2011 to 2022 (source: Pure) and B) cumulative number of WM citations in Scopus and PlumX engagements for the assessment period 2017-2022. Data includes publications (~30 per year) and PhD theses (~4 per year) by IHE-Delft staff affiliated with WM.

Co-authors of WM publications included 548 external researchers, indicating that WM academic staff are well embedded and recognised in the scientific community. Figure 46 in the Appendix C.3 illustrates the diversity and strength of these scientific collaborations, including close national collaboration with IHE Delft, KWR, Deltares, and other universities such as WUR, University of Twente, and Utrecht University, as well as the strong international ties with other leading universities in the water domain, such as ETH Zürich, University of Exeter, and Colorado State University.

The scientific excellence of WM staff is recognised by the various personal research grants and awards that individual team members have received during 2017-2022, including an NWO-Veni (Lompe, 2022; Zietzschmann, 2020; van der Ent, 2017), an NWO-Vidi (van Halem, 2019), an NWO-Aspasia (Coenders, 2019), an AGU Fellowship (Uijlenhoet, 2020) and an AGU International Award (Savenije, 2017). Other awards include outstanding Editor Award of HESS journal (Coenders, HESS), IWA Fellowship (Langeveld) and the First Place Award for outstanding achievements in BattleDIM (Abraham, 2020). Aside from personal grants and awards, team efforts have also received recognition. In 2020, Spanjers and van Lier received the Holland High Tech Award for their invention of electrochemical recovery of ammonium from concentrated streams. In 2021, Van der Hoek, Rietveld, and Heijman jointly received the Waterinnovatieprijs for AdOx water treatment technology. In the same year, an MSc student co-supervised by Hrachowitz and Schoups won the Jim Dooge Award for her paper in HESS journal on climate-induced changes in river discharge in Alpine catchments. These examples illustrate – in addition to the increasing number of funded collaborative projects (Table 36 in Appendix C.3) – that the team-PI model is stimulating collective excellence.

Figure 28 Global network map of WM's research collaborations based on co-authorship of publications (source: https://research.tudelft.nl/en/organisations/water-management/network-map/*).*

The societal relevance of WM research is demonstrated by the wide range of SDGs that our applied research contributes to (Figure 47 in Appendix C.3). With a significant focus on the Global South, the department contributes to water, climate, energy, and agriculture-related SDGs across regions such as sub-Saharan Africa, India, South-East Asia, and South America, as exemplified in our case study on "Rainfall mapping in Sub-Saharan Africa". The global network of WM's research collaborations is visualised in Figure 28.

The use of WM knowledge, tools, and technologies is illustrated by more than 30,000 engagements (based on PlumX Metrics; Figure 27B). To maximise the societal

impact of our research, our collaborative projects involve working together with a broad diversity of academic and non-academic partners. For example, our connections with the Dutch water sector are strong and growing, including collaborations with water companies, water authorities, research institutes, engineering consultants, and the Dutch government. Table 37 in Appendix C.3 gives an overview of our non-academic collaborators. Our case study on “Circularity in the urban water cycle” (see Appendix A.4.1) provides an example of how close ties with industry have accelerated impact of innovative research breakthroughs at the department. Examples of public outreach and communication to the wider public include lectures at Universiteit van Nederland and MuseumJeugdUniversiteit (e.g. by de Kreuk, van Halem, and Hut), TV and radio appearances (e.g. rolfhut.nl), and citizen science projects and spin-offs (e.g. smartphones4water.org). Between 2017 and 2022, WM staff made a total of 171 media appearances.

9.6.2 Theme: Water and Energy in Urbanising Deltas

WM research contributes to water and energy sustainability in urbanising deltas in the fields of urban drainage, water treatment, artificial intelligence, thermal energy recovery, and more. Applications of Real Time Control resulted in improved operation of urban drainage and wastewater treatment systems (Van der Werf, Langeveld, Kapelan), and model predictive control and deep learning tools were developed for optimally managing pumping and freshwater flushing in irrigated polders (NWO/TKI, Abraham). Machine learning and AI were also used for modelling and managing drinking water and urban

Figure 29 A) Scholten in a sewer for the NWO SewerSense project and B) Visit of our King and Queen to the NWO LOTUSHR pilot site in Delhi, India.

drainage systems (Taormina, Aidro Lab; Table 36 in Appendix C.3), and for detecting and preventing failures in urban water infrastructure, such as the automatic detection of sewer pipe defects from CCTV footage in the NWO-funded SewerSense project (Scholten). Other examples include the use of multi-criteria decision analysis (with Waternet) and serious gaming for improved stakeholder engagement and decision support, the latter as part of the EU-funded WaterAgri project.

Solutions for managing water storage and infiltration in cities were studied from different perspectives, including the re-use of urban stormwater via biofiltration and aquifer storage (EU Climate KIC; van Breukelen, Rietveld), and the use of decentralised urban managed aquifer recharge in Ghana (African Water Corridor; van Halem, Abraham; Table 36 in Appendix C.3). The close collaboration with the Green Village on campus is noteworthy, particularly for demonstration-driven research such as “Het Hitteplein” (Coenders, Rutten).

Important achievements were earned in nutrient and energy recovery from wastewater, and a new Academic Career Track colleague (Palmeros Parada) recently joined WM to further strengthen the team in this area of circularity. For example, the water-reuse projects NWO LOTUS-HR and Saraswati2.0 focus on smart treatment and resource recovery, with pilot systems in India (see Table 36 in Appendix C.3). In an NWO WOTRO Urbanising Deltas of the World project, water reuse strategies for Maputo (Mozambique) were investigated (Rietveld, van Lier). The EU ZEROBRINE project demonstrated various techniques to valorise brines from membrane processes applied to chemical industrial wastewater, recovering purified salts for reuse (Rietveld, Spanjers). Recent work on combining anaerobic treatment with solid oxide fuel cells (Lindeboom, Spanjers, van Lier) allows for energy generation from wastewater and increases circularity. In direct cooperation with Biothane-Veolia, the anaerobic membrane bioreactor technology matured to full-scale treatment of a variety of wastewaters, while also targeting water reuse. Our leading position in anaerobic treatment processes is underlined by the 780 participants joining the 16th IWA Anaerobic Digestion Conference, organised at TU Delft by van Lier and de Kreuk.

Various contributions were made to the water-energy nexus. An example is the extraction of aquathermal energy from drinking water (Van der Hoek), a key technology for the energy transition and for the Dutch National Climate Agreement (Klimaatakkoord). Similarly, WM leads projects on Aquifer Thermal Energy Storage Systems (EU PUSH-IT project, Table 36 in Appendix C.3) and extraction of heat and cold from surface water (Bloemendal). In the transnational ENLARGE project, WM researchers developed an optimisation model that determines the right mix of urban heating technologies to support the energy transition in Amsterdam, considering carbon emissions and impacts on freshwater resources (Abraham, van de Giesen). In the EPIC Africa project (Table 36 in Appendix C.3), long-term energy system planning is coupled with agricultural and water infrastructure decisions through water-energy-food nexus modelling for Ghana, Burkina Faso, and Kenya.

Research in this theme also addresses barriers to the adoption of water-smart solutions, such as organisational, regulatory, social, and economic aspects. For instance, the EU-funded WIDER UPTAKE project develops a roadmap for implementing water-smart solutions for water reuse and resource recovery, with case studies in Europe and Africa. Another project, NUWTS, funded by TKI Water technology and eight companies, focuses on designing urban water transport infrastructure based on resource recovery and water conservation strategies.

As water challenges in growing cities across the globe are increasingly attracting attention, WM will be expanding the theme “Water and Energy in Urbanising Deltas” in the coming years, e.g. to include heat networks, urban heat islands, water infiltration, and storage in cities.

9.6.3 Theme: Water, Health, and Disaster Preparedness

This theme focusses on developing new technologies to reduce and manage the health risks of water-related hazards (e.g. pollution, landslides, floods). Significant impact was generated on water treatment of emerging contaminants. An example is the AdOx project, which developed a novel approach for organic micro-pollutant adsorption to zeolites and subsequent regeneration via oxidation (Heijman, Van der Hoek, Rietveld). Other examples include transport of nanoplastics in sand filters (NWO-Veni Lompe), electrochemical PFAS degradation (TKI Watertechnology), and the removal of arsenic from groundwater (NWO DELTAP Bangladesh). Sewage water treatment and sanitation is also an important topic within WM, with research on anaerobic digestion, non-sewered sanitation in high-density areas (e.g. Nairobi), and aerobic granular sludge and tertiary treatment, such as inactivation of antibiotic-resistant bacteria by iron electrocoagulation in the NWO LOTUS-HR project (Table 36 in Appendix C.3).

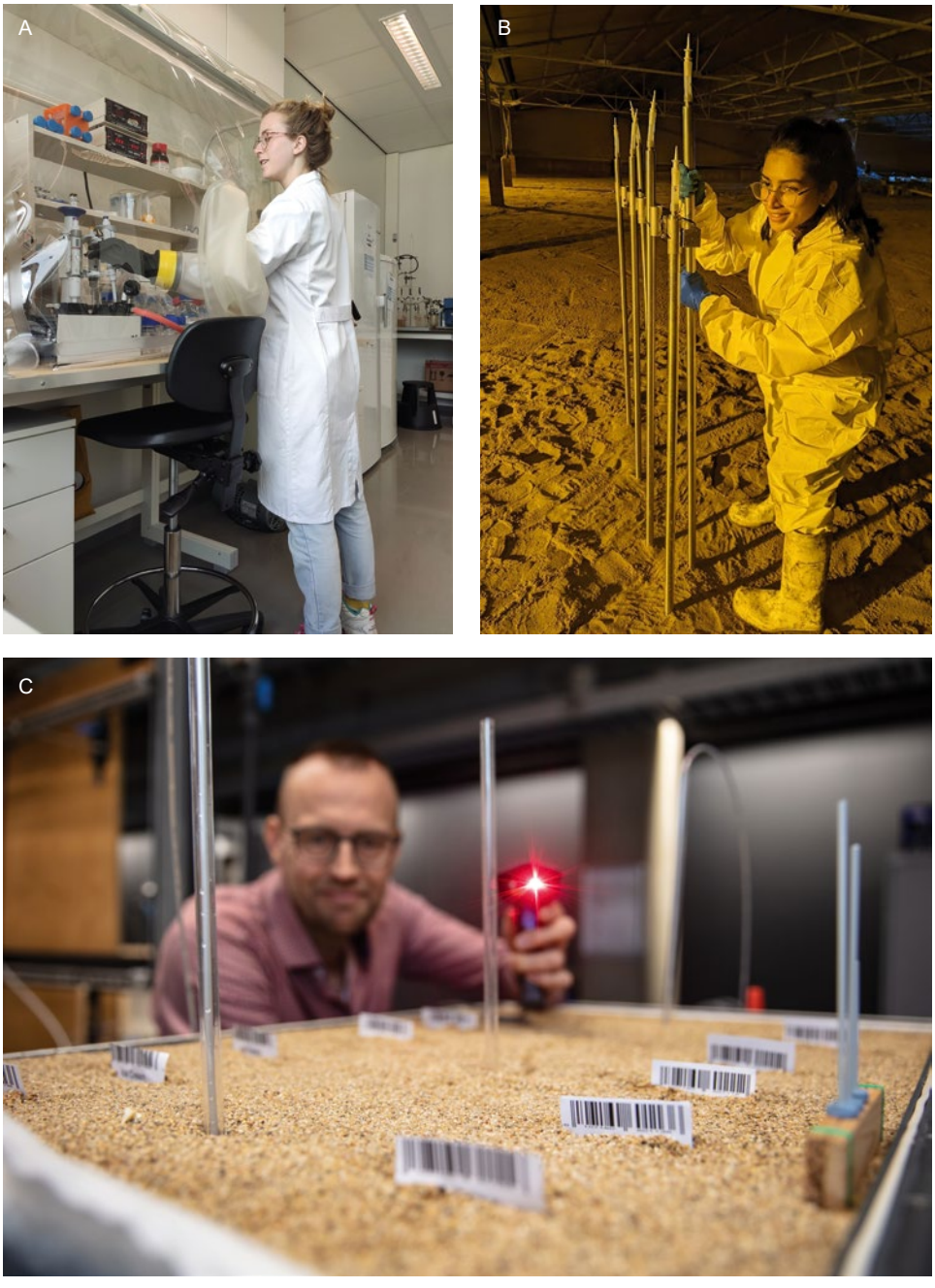


Figure 30 Experimental work A) in lab for the NWO Open Mind project "from waste to value", B) on a full-scale filter for the NWO SSF Next Century project, and C) synthetic DNA tracer experiments.

A topic that has received increasing attention is groundwater quality. In the NWO SEALINK project, surface water and groundwater flows carrying pollutants from land to sea were measured on Curaçao with the goal of improving water management to protect coral reefs. In addition, two NWO projects were granted to unravel removal mechanisms in (groundwater) filters for drinking water treatment (RedOx Filter & SSF Next Century; Table 36 in Appendix C.3). An NWO Open Mind grant was also awarded to PhD candidate Goedhart for a novel method for recovering iron from groundwater. A novel groundwater tracing methodology based on DNA microparticles (Foppen, Bogaard) was developed in the NWO WaterTagging project, as well as a methodology for measuring groundwater flow velocities using distributed temperature sensing (NWO, Bakker).

Societal impact was generated on the topic of water pollution in river basins. An example is the Brantas river project (Ertsen), an Indonesian-Dutch collaboration funded by the Sustainable Water Fund in which water quality management of a large Indonesian river basin is strengthened by linking water quality monitoring procedures, policy measures, and stakeholder interests. Another example is development of a low-cost water quality monitoring system for the Ayeyarwady River in Myanmar (Bogaard, Rutten).

During the COVID pandemic, surveillance of sewage water emerged as a new research field, leading to the development of early warning systems for other diseases, such as monkeypox. WM staff are leading scientists in this field (Medema and Langeveld) and participate in the Convergence Pandemic and Disaster Preparedness Centre (Rietveld). Disaster preparedness topics also include research on landslide hazards (Bogaard, Hrachowitz), dike failure early-warning systems (e.g. DOMINO project), and river flooding. In response to the floods in Limburg in 2021, a research working group was put together under the Delta Futures Lab at TU Delft in close collaboration with stakeholders and other universities in and outside of the Netherlands (Rutten). Results were translated into policy advice. Other research on climate adaptation led to a revision of existing cross-border water agreements between the Netherlands and Germany (Mostert). Finally, the department contributed to the cybersecurity of water distribution systems (Taormina), creating software tools and datasets to emulate the effects of cybersecurity attacks on water distribution systems and to detect anomalies caused by intrusions and failures. These tools were shared with both researchers and practitioners, including cyber-security firms and TNO.

The theme “Water, Health and Disaster Preparedness” is expected to grow further the coming years, partly due increasing pressure on our water resources (e.g. RIVM and VEWIN reports, Water Framework Directive goals 2027) and partly due to exciting developments in scientific methods that are accelerating the field (e.g. ML/AI, qPCR).

9.6.4 Theme: Water, Food and Climate

The scope of this theme is to contribute to a better quantitative description of the hydrological cycle, facilitate flood and drought management in river basins, and support sustainable agriculture. Significant achievements were earned in measuring precipitation and evaporation. One example is the Trans-African Hydro Meteorological Observatory (TAHMO; van de Giesen), which established a network of 650 weather stations in over 20 sub-Saharan countries, and is, with 3 billion data points, the largest provider of in-situ weather and climate data for Africa. Another example is rainfall estimation using opportunistic sensors, such as commercial microwave links from mobile telecommunication networks, with successful applications completed in Europe, Africa, and Asia (Uijlenhoet). Advances in evaporation and land-atmosphere measurements were made by distributed temperature sensing (DTS), with extensive funding from NWO (Coenders).

Research within the Plantenna project (Table 36 in Appendix C.3; ten Veldhuis, Uijlenhoet) develops novel sensors to detect early signs of drought stress in plants, with the related FruitFrost project aimed at improved understanding and prediction of frost in orchards. Interactions between climate and vegetation have also been studied at larger scales, resulting in a better understanding of atmospheric moisture sources of precipitation extremes and the associated role of vegetation feedback for the generation of droughts (NWO Veni and Refugees in Science, van der Ent). New modelling techniques have been developed to account for interactions between climate and vegetation in river basins and to predict adaptation of vegetation to climate change in several projects funded by NWO and Rijkswaterstaat (Hrachowitz).

Figure 31 A) Pilot site of the NWO AgriMAR project, B) student at work in Ghana for the H2020 TWIGA project.

In the field of water and agriculture, the TWIGA project (Table 36 in Appendix C.3; van de Giesen) developed climate services to increase the productivity of smallholder farmers. A spinoff of smallholder socio-hydrology research in WM, the Makara initiative (led by Pande and supported by Netherlands Enterprise Agency and the CSO Solidaridad) has an ongoing project with smallholders in India to bridge the digital gap in agricultural supply chains by empowering farmers with water-centric risk intelligence. Water use and efficiency in irrigated agriculture were investigated using agrohydrological models to improve irrigation efficiency and optimise agricultural water management (Pande, Abraham, Schoups). The NWO AgriMAR project (van Breukelen, Medema) addressed water quality in agriculture and generated new insights into the removal of agrochemicals and plant pathogens from agricultural drainage water using managed aquifer recharge (MAR), with the treated water providing a new source of irrigation water in the coastal Netherlands. More recently, a new project, AGRICOAST (Table 36 in Appendix C.3), started investigating aquifer recharge in saline environments on the Dutch island of Texel.

WM also develops novel hydrological modelling tools to support water management in river basins and aquifers. For example, the eWatercycle project (Hut) has developed a modular open-source software environment for hydrological modelling that is freely available to the international community (GitHub) and is actively used in MSc and PhD research at WM. Open-source software for groundwater time-series analysis (Pastas github) was developed, and a book was published on analytical groundwater modelling with Python (Bakker). WM also co-edited and contributed to the 2021 Handbook of Water Resources Management (Van Nooijen, Ertsen). Finally, novel techniques were developed for making optimal use of remote sensing and citizen-science data in hydrological modelling (Schoups, Bastiaanssen).

Within the theme “Water, Food, and Climate” interesting cross-linkages exist with the other themes, as circularity (of water, nutrients, etc.) often involves agricultural applications. As such, WM is actively encouraging multi-disciplinary research in the Water-Food-Energy Nexus across the department.

9.7 Strategy for the next six years

In this section, we outline our strategy for the next six years based on (i) input from all staff members collected via two departmental strategy meetings (on 10 February 2023 and 6 April 2023), and (ii) an international work visit to KU Leuven (KUL) and Ghent University (UG) in Belgium (on 11 May 2023). Overall, we do not anticipate any big shifts in strategy, but instead a continued development and strengthening of current strategic choices, such as the team-PI model. In the coming years, research at WM will focus on societal challenges centred around water, including climate change, population growth, urbanisation, the energy transition, the circular economy, (emerging) water contaminants, resource recovery, and digitisation (i.e. AI, big data) in the water sector. The following paragraphs highlight specific strategies to capitalise on these trends, considering strengths [S], weaknesses [W], opportunities [O], and threats [T] identified in the SWOT analysis (Table 26).

Table 26 SWOT analysis for department of Water Management

	Strengths	Weaknesses
Internal view	• Application-focused approach addressing fundamental questions. • Diverse, high-quality water expertise in one location with linked data (water lab, field) and modelling research. • Integrated solutions through collaborations. • Leading global collaborations and extensive worldwide network. • Strong alumni ties, fostering research collaboration and MSc thesis work. • Robust industry connections. • Supportive and collegial environment. • Proven success in securing research funds. • Strong international reputation shapes identity and attracts top talent.	• Image problem: grey/engineering image while the world is increasingly asking for green and socially acceptable solutions. • Better communicate to the outside world what we do compared to others. • Process of recognition and rewarding of academic staff could be improved. This is mainly a faculty and less a department issue (HR policy chapter). • Still room for improvement regarding diversity in the group. • The involvement of support staff (lab personnel, administration, project management, finances, communication) could be more strategic. • Integration of two sections through joint projects could be further developed.
	Opportunities	**Threats**
External view	• AI, big data, digitalisation continuing trends in water sector and research • Stricter environmental laws and policy drivers (e.g., surface water, drinking water quality, discharge effluents, sustainable soil) • Circular economy of water: e.g. tapping into municipal effluents • Pressure on global water resources will require increasing scientific knowledge and technological expertise on water management • Energy transition: e.g., heat storage in water bodies	• Increased competition from other institutes and universities (e.g. groups from other disciplines deciding to increase their presence in the WM area). • Potential shifts in governmental policies (e.g. limiting the influx of foreign students, internationalization, etc.) • Potential changes in societal needs and labour market (difficult to find people who want to do academic jobs) • Internal collaboration not promoted by funding bodies such as NWO, threat to team-PI model

9.7.1 Organisation and hiring strategy for the next six years

A unique strength of the department is its great diversity water expertise within a single department [S]. In comparison, UG and KUL have water expertise dispersed across different departments (e.g. water resources and water technology) and sometimes even across different campuses (KUL). To leverage this advantage, we will continue the process of integrating the different sub-disciplines within the department [from W to S]. One practical measure involves a planned reorganisation of office space with the goal of moving people (and subdisciplines) physically closer together. Another is the periodic organisation of department-wide strategic meetings to foster a common identity and purpose.

Our goal is to maintain and further develop the current team-PI model, allowing for maximum flexibility in forming collaborative teams to respond to new societal needs and funding opportunities [O] and outside threats [T]. While collaboration between sub-disciplines within the department is increasing, there remains untapped potential for creating added value and competitive advantages by fostering interdisciplinary collaboration. To unlock this potential, we intend to organise match-making sessions within the department to increase awareness of each other's work and expertise, as well as to brainstorm collaborative opportunities. This can involve (i) addressing scientific and societal challenges from a multi-disciplinary angle, for example, integrating hydrological

and water treatment expertise for managing water pollution in river basins [O], and (ii) sharing and exchanging methods used in different sub-disciplines, such as optimisation, AI, and machine learning [O].

To bolster resources needed in analytical chemistry and bio-analytics with strategic research on water treatment and water quality [W], our WaterLab is currently being extended with an additional 150 m^2 Environmental Engineering education lab, which will be completed in 2024. The expansion of support staff has already been initiated in recent years (see Appendix B.1). Shared infrastructure (e.g. WaterLab), network (e.g. collaboration with drinking water companies, water boards and the Ministry of Water and Infrastructure), access to institutes and existing collaborations (Pro2tech, BEI, Design for values, Delft Global, pandemic and disaster centre, Leiden-Delft-Erasmus) contribute to a fruitful, high-quality environment that allows (junior) WM staff to flourish.

WM remains committed to promoting diversity in hiring decisions. We note that recent hires of the past year (Sectorplans, replacement of retiring staff) within the department have been fully gender-balanced (five female, five male) and nationality diverse (four non-Dutch, six Dutch). While the department has made concrete steps towards gender and age diversity, as well as internationalisation (i.e. replacing retiring Dutch staff with international young talent), there is room for improvement [W, O]. During our work visit, we discovered that similar discussions about diversity play an important role at KUL and UG, which also recognise that further steps are needed. We anticipate a gradual process, within the department and the Faculty, marked by increasing awareness of the importance of diversity in the broadest sense, i.e. extending from gender and age to culture, background, and personality. Leveraging the Faculty's initiatives to improve academic culture and equity, diversity and inclusion, measures such as bias training (as done at KUL) and workshops on team diversity can facilitate this process.

9.7.2 Publication and communication strategy for the next six years

In the coming years, we will remain committed to the open-source publication of all our scientific outputs (journal articles, data, software). Efforts will be intensified to communicate our research outcomes beyond the scientific community, emphasising strong market connections and collaborations with water companies (e.g. Dunea, Vitens, WML), research institutes (e.g. KWR, Deltares, KNMI), engineering consultants (e.g. HKV, Witteveen+Bos, RHDHV), technology providers (Nijhuis, Biothane, Paques, Lenntech), and government (e.g. Rijkswaterstraat, water boards). Furthermore, to improve our image and increase our visibility and reach [W], our newly established departmental communication team will coordinate communication and public outreach, taking strategic steps such as creating an inventory of staff expertise, directing press inquiries to relevant staff, and proactively publishing department activities and output related to water-related topics in the (social) media. In addition, WM will continue to play a leading role on the international stage, e.g. by actively participating in and organising international conferences, as was recently done for the Delft Water Summit for Global Development 2022 and the UN 2023 Water Conference in New York.

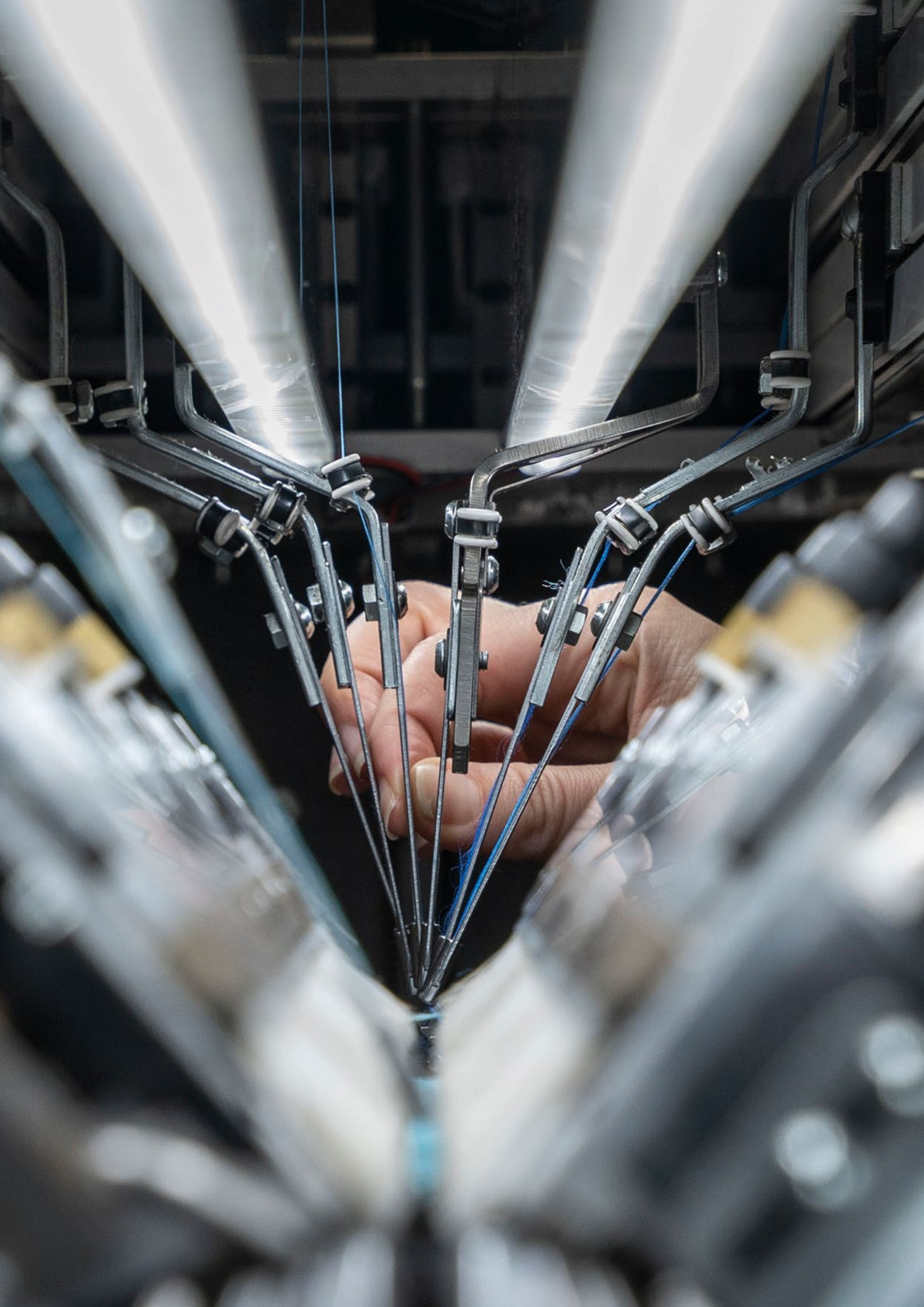
9.7.3 Collaboration, funding and valorisation strategy for the next six years

While the team-PI model fosters internal collaboration, this does not by itself guarantee opportunities for acquiring funding from bodies such as NWO and the EU, which typically require extensive external collaboration [T]. However, we believe that expertise in the WM department will remain crucial for tackling current and future societal challenges, as there are myriad opportunities in water research and its broader connections with other sectors [O]. Within the theme "Water, Health, and Disaster Preparedness" key scientific challenges that will be addressed include, among others, decentralised treatment, electrochemical methods for water treatment and resource recovery, and emerging contaminants in the environment and in drinking water (e.g. driven by new legal limits for

PFAS concentrations), and flood risk. Within the theme “Water, Food and Climate”, key scientific challenges include, among others, developing new hydrological observations and models, understanding and quantifying the role of vegetation in the water cycle, future-proof agriculture under climate change, and better management of floods and droughts in river basins. Within the theme “Water and Energy in Urbanising Deltas”, key scientific challenges to address include new methods for the digitisation of urban water infrastructure (UWI) and water sector (both drinking water and urban drainage), smart methods and solutions for UWI adaptation to climate change and urbanisation, and sustainable water use with aquathermal energy extraction and storage [O].

Our hiring strategy will be based on a continuation of recent strategic hiring that has targeted the three cross-disciplinary WM research themes and both sections equally. In the Water Resources section, two Assistant Professors have been recruited, one on Urban Hydrometeorology (for Climate Action) and another on Environmental Water Quality with a focus on geohydrology, while the vacancy for Urbanising River Deltas is yet to be filled. In the Sanitary Engineering section, three Assistant Professors have recently been hired for Resource Recovery, Heat Networks, and Water & Health.

Recent project acquisitions and proposals in the making (2022/2023) provide an additional glimpse of future research directions and team-PI collaborations at WM [W to S] (Table 36 in Appendix C.3). Our overall funding strategy will continue to aim at a mix of personal grants and consortium-based projects. Our work visit to KUL revealed that collaboration with societal partners and governing bodies is comparatively strong in the Netherlands, which provides an incentive for closer collaborations with water boards, technology providers, and end-users to increase WM’s societal impact in the Netherlands. Since 2017, we have participated in approximately nine Top-Sector (TKI) funded projects that utilise these collaborations and will continue to respond to the needs of water boards, utilities, and industry. Internationally, the recently granted EU projects TEMBO and EPIC Africa, as well as the cross-university GROW application (four WM PhD candidates), will further boost WM research in Sub-Saharan Africa. With these, and our extensive partnerships globally, we are well placed to contribute to the research that will drive the EU’s Global Gateway programme.



10. Department of Materials, Mechanics, Management & Design

10.1 Introduction

The department Materials, Mechanics, Management & Design (3MD) focuses on design, management, mechanics and materials principles of civil infrastructures and buildings. These structures are analysed by means of a multi-scale approach that governs the entire lifecycle from development, design, testing, building, maintenance and operation to reuse or recycling. Figure 32 shows the department's structure, broken down into its three sections: Materials and Environment (M&E), including the micro-mechanical laboratory (Microlab), Applied Mechanics (AM) and Integral Design and Management (IDM), the core disciplines of which focus on three scales, namely the material scale, structural scale, and system scale, respectively. Furthermore, three connecting themes have been defined: (i) **design** from the materials scale to systems scale, (ii) **sustainability** including circular approaches and (iii) **digitalisation**. By analysing the three connecting themes by means of a multi-scale approach, a coherent research programme can be established for the department. Advanced and integrated use of data, experiments and simulations characterises the research programme, which has a broad scope and takes a deep, multi-scale approach. The department's staff breakdown can be found in Appendix B.1.

This report was compiled by a writing team consisting of junior and senior staff members from the three sections, in consultation with the board of the department and with input from all staff members.

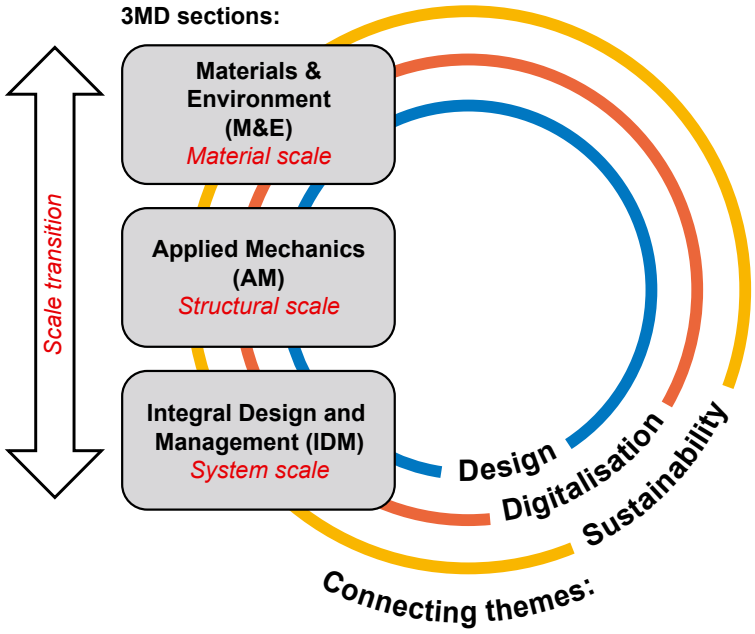


Figure 32 Department structure, sections and connecting multi-scale themes and technologies for 2017-2022.

10.2 Mission and strategic aims over the past six years

In this chapter, we report our mission statement and strategic aims of the past six years. These are aligned with the strategy of the Faculty and TU Delft's strategic framework. The aims also form the basis for the strategy for the next six years.

10.2.1 Mission

In general, the 3MD Department aims to:

- conduct world-class fundamental, application-oriented and societally relevant research supported by excellent and unique experimental and numerical facilities; this research has a mono-, multi- and trans-disciplinary character;
- create an open, inclusive, professional and stimulating environment for students, researchers, and lecturers to develop to their full potential;

More specifically, the 3MD department strategically aims to:

- optimise the resilience of buildings and infrastructures to increased loading, natural hazards, and anthropogenic threats;
- improve the sustainability of buildings and infrastructures by producing comprehensive solutions to reduce negative environmental impact;
- advance the transition to renewable energy systems from a materials, mechanics, management and design perspective;
- foster a technological transition by developing innovative, smart materials, novel construction technologies, advanced computational techniques, and design principles to create safer buildings and infrastructures with increased performance and functionality.

These strategic aims are closely linked to the societal challenges defined in strategy of the Faculty. Many of the United Nations' Sustainable Development Goals (SDGs) can be connected to our mission to create a better, safer, and more sustainable living environment for society. As presented in section 10.1, research activities are carried out in the three sections at the three corresponding scales of M&E (material scale), AM (structural scale, including structural components), and IDM (integral systems scale) with common threads running through connecting themes and technologies, namely (i) multi-scale design, (ii) sustainability/circularity and (iii) digitalisation by adequately combining physics and data. These research activities, both in the mono-disciplinary sections and the multi-scale, multi-disciplinary themes and technologies, connect to the highlighted department aims. 3MD has profound fundamental expertise with high international visibility, as well as strong relationships with construction and design practice (see section 10.6). Therefore, the research work is fundamental and applied in nature and should keep pace with the highest levels in the international scientific community and with the front line of technical innovations and challenges. 3MD has a broad and multi-scale research portfolio and is also deeply involved in BSc, MSc and PhD education, providing basic knowledge as well as research-driven education.

10.2.2 Strategy

The abovementioned strategic aims of the department are aligned with the societal challenges identified by the Faculty and major civil engineering challenges in general. Civil engineering provides our society with solutions to major societal challenges related to climate change, the energy transition, resource depletion, and ongoing urbanisation (see Faculty strategy 2019-2024). In the 3MD department, research efforts in the assessment period have been focused on the societal themes climate change, energy transition, and resource depletion.

The construction industry has a major environmental impact. Production and processing of construction materials is energy consuming, resulting in a significant carbon footprint as well as other harmful emissions and waste materials with a negative impact on the environment. Furthermore, the volume of materials used is enormous, with the transport of construction materials only adding to the impact. Moreover, climate change itself directly affects our built environment. That is why 3MD has first defined research activities related to climate mitigation, such as the development of durable and sustainable materials, smart technologies, and circular construction strategies in order to reduce raw material use. Secondly, activities related to climate adaptation have been defined, such as the design and development of adaptive materials and structures (smart, 'bio-adaptive/receptive, and nature-inclusive), and integral strategies and solutions. Infrastructure systems should be designed and managed such that they are able to cope with and successfully recover from climate-induced hazards. A multi-scale and integral design approach has been followed.

At the material scale, research is conducted on self-healing materials, extending the lifecycle of structures, high-performance materials, reducing volumes of raw materials used, innovative fabrication techniques, additive manufacturing, and more. In order to reduce the carbon emissions associated with construction, materials with low-impact binders are developed, such as geopolymers made from waste materials or calcined-clay-based binders.

At the structural scale, research is conducted on safe, reliable, and climate-change-proof (infra)structure (e.g. houses, historical assets, bridges, quay walls, etc.) by gaining an in-depth understanding of failure mechanisms in structures for multiple hazards (e.g. earthquakes, soil subsidence, impact load). Innovative numerical modelling techniques are developed for novel material systems (e.g. metamaterials) and structures, while development of simplified approaches for engineering practice is also considered.

Machine learning and advanced sensors for material health monitoring are used and developed to ensure safe and low-maintenance structures. Furthermore, the department is working on topics such as multifunctional structures, heat-absorbing facades, green concrete structures, and low-impact construction technologies for an adaptive and resilient built environment. 3MD is also contributing to structural fragility and damage research for induced seismicity problems in Groningen and other mining activities. Tiered analytical and computational models have been developed for masonry building response due to ground movements and calibrated against multi-scale laboratory tests. These research activities help authorities make damage forecasts and decisions.

At the system scale, research is conducted on innovative integral design and management processes spanning the overall integrated project life cycle, including the adoption of circular and sustainable solutions in infrastructure, the development of smart ways to improve circularity within construction processes, innovative engineering asset management to extend the lifecycle of infrastructure and reduce the impact of maintenance, and the resilience of built infrastructure to natural and man-made hazards. As systems are of a socio-technical nature, it is important to acknowledge how social and human capital are integrated in the design and construction of structures and infrastructure. The department is working on topics from a people-oriented perspective, nurturing project leadership, stakeholder engagement, integrated project delivery, team integration and human-computer interaction. These research activities produce impactful outputs that support infrastructure authorities, engineering consultancies, and policymakers in the decision-making process.

The 3MD department contributes to the energy transition in two ways, namely through the (i) multi-scale design of (infra)structures for renewable energy systems, and (ii) the design of energy generating and transmitting materials and structures. Examples at the material scale include self-healing pavements with electrical vehicle-charging capabilities, energy generating, harvesting (bituminous) pavements and structures, and energy-storing materials that make use of phase change materials (PCMs). At the structural scale, research is conducted on the computational modelling of wind turbines, energy piles, geothermal energy systems, and structural batteries.

Regarding resource depletion, the 3MD department researches reduced material use through advanced design techniques for slender and lightweight composite structures, adaptable and re-usable materials and structures, techniques for 3D-printing of structures with reduced material use and formwork through novel digital manufacturing (e.g. flexible formworks), use of AI and advanced numerical modelling tools to reduce use of materials, self-healing materials, materials with improved recyclability, smart asset management, and circular construction models, both from a technological and an economic point of view.

The abovementioned societal challenges are coupled with the relevant scientific challenges and organised in the three mono-disciplinary sections (M&E, AM, IDM) and within the three interdisciplinary connecting research themes and technologies regarding design, sustainability/circularity and digitalisation. The mission statement helps the department to respond to changes in academia and society and make decisions that align with our vision.

10.3 Follow-up from previous assessments

In this section, we briefly explain the recommendations resulting from the previous full-term research assessment and the mid-term research assessment and demonstrate how the 3MD department has addressed and is addressing these points.

10.3.1 Heterogeneity, internal and external collaboration, and visibility

After the split of the former Structural Engineering department, which was assessed as a particularly heterogenous department, 3MD sought to improve cohesion within the new department by:

- defining three connecting research themes between the department's sections as described in the previous two sections of the document (see Figure 32);
- carefully defining new staff positions, enabling interaction between sections within and/or outside the department;
- relocating the entire department to one floor;
- organising regular staff meetings in which staff members pitch their research topics and collaborative efforts.

These efforts have been successful, and the midterm assessment committee considered the 3MD department coherent, despite its three separate sections, with strong and societally relevant cross-cutting themes. Collaboration has been initiated and/or strengthened with other departments during the assessment period. With the Geoscience and Engineering (GSE) department, several collaborations have started in the fields of sub-surface engineering and geothermal engineering. Ties with the Engineering Structures (ES) department have been strengthened by collaborating in the fields of the mechanics of fibre-reinforced polymeric materials, cementitious and bituminous materials, and structural response to earthquakes, in particular with the groups Steel & Composite Structures, Concrete Structures, Pavement Engineering, Dynamics of Structures. Furthermore, strong connections with the ES department exist in sharing lab facilities. With the Hydraulic Engineering (HE) department, research projects on flood protection in relation to integral design have started. In the context of Construction Management and Engineering (CME), cross-faculty collaboration was further strengthened with the Faculty of Architecture and the Built Environment and the Faculty of Technology, Policy and Management. Close collaboration with the Faculty of Electrical Engineering, Mathematics and Computer Sciences (EEMCS) was expanded by setting up Delft Blue, a new supercomputing facility and by taking the initiative for establishing the TU Delft Artificial Intelligence (DAI-Lab) SLIMM-Lab on the use and development of machine-learning techniques for smart materials modelling. This is a perfect example of how the department can leverage its core expertise in collaborations with another faculty (EEMCS) to work on cross-cutting themes. Staff members have been involved in current networks with industrial parties (e.g. NAM, Bouwend Nederland) and the government (e.g. ministries and governmental advice committees), research institutes (TNO, Deltares), infrastructure agencies (e.g. RWS, ProRail), but also by adding new networks (Provinces, industry, network fire safety, Amsterdam Metropolitan Solutions (AMS) institute, BTIC/TKI Bouw &Techniek). In the context of the national Sectorplans Technical Sciences I and II, new research activities were discussed and aligned with the civil engineering groups at the University of Twente and TU Eindhoven, expanding internal and external collaboration.

10.3.2 Diversity and academic culture

When the former department was split up in 2018, only 11% of 3MD staff (Full, Associate, and Assistant Professors) was female. The share of female staff members has only slightly increased to 17% since, even though multiple measures have been taken to improve the gender balance. One of the female young staff members who joined the department unfortunately decided to leave because of personal reasons. Despite this setback, 3MD is determined to improve the gender balance by strictly applying the measures mentioned in section 10.4. 3MD strives to be an inclusive and safe environment for all colleagues and students. With respect to social safety, general measures (discussion in staff meetings and in bilateral meetings such as R&D meetings encouraging colleagues to speak out) and targeted measures were taken. Active participation of one department member in the Faculty's Academic Culture Committee and frequent communication on diversity and inclusivity within the department resulted in an increased awareness of the importance of these issues.

10.3.3 Strengthening specific research fields

According to the full-term review, the Structural Design group (part of the AM section) and the Integral Design and Management (IDM) section had to strengthen their research portfolio, due to their heavy involvement in education. Firstly, Structural Design was strengthened by appointing a Full Professor of Structural Design and an Assistant Professor of Parametric Structural Design and Digital Fabrication. These new staff members have a more academic profile than the present staff members, who have stronger background in industry. This enables the group to create a more visible profile and improve its scientific record in research. A research agenda was formulated with topics such as sustainable and circular construction and digital fabrication and robotics. Secondly, within the group IDM three new Assistant Professors were appointed on the topics of Engineering Asset Management, Transdisciplinary Design of Infrastructures, and Economics of Civil Infrastructures. Furthermore, IDM has increased its focus on the use and development of digital methodologies for comprehensive design and project management. Appointment of these staff members and a shift in research focus in both groups will strengthen the research portfolio. Furthermore, a fruitful link with other groups in the department could be made because the new themes and positions align with the research agenda of the department with the connecting multi-scale themes of design and digitalisation.

10.4 Strategic process of the past six years

10.4.1 Adjustment of strategic aims during the assessment period

The strategy and strategic aims, as defined in section 10.2, were mainly confirmed during the assessment period. A number of developments enabled the department to make choices and decisions that were more closely aligned with our vision. First, the national “Sectorplan” Technical Sciences I, aimed at strengthening the core disciplines in civil engineering, made it possible to create four junior staff positions on highly relevant topics in the 3MD programme (material health monitoring, multi-scale modelling of additively manufactured materials, mechanics of nano-structures materials, robust nonlinear computational modelling). Secondly, the Delft Artificial Intelligence laboratory (DAI-lab) SLIMM-lab was established, which boosted the connecting research theme digitalisation. Thirdly, additional first-stream funding and the sound financial situation of the department itself made it possible to significantly invest in the Microlab in order to remain one of the leading laboratories with high-tech equipment for scientific materials research (e.g. X-ray diffraction and X-Ray fluorescence devices for advanced characterisation of materials). To strengthen parametric design and digital fabrication of structural components, an industrial knitting machine was purchased. Furthermore, a special material health monitoring laboratory for advanced sensing techniques was established within the Microlab. Fourthly, to stimulate the use of digital techniques such as VR/AR/XR, novel imaging techniques, robotic devices, and additive manufacturing, the department proposed a Digital Construction laboratory, for which a collaboration has started with the department of Transport and Planning in order to share expertise. Furthermore, 3MD participated in setting up the high-performance computing cluster DelftBlue, which is of paramount importance for the large, complex, and often multi-scale calculations needed in the 3MD programme. Finally, thanks to high-end contract research funding, new research lines related to mechanics of masonry material and masonry structures have been defined, including the establishment of the Masonry lab, which can perform materials tests and full-scale tests on walls and two-story buildings.

10.4.2 Open science

In publishing research results, 3MD applies the TU Delft and CEG guidelines for open science. 3MD has proactively assigned delegates to each section to communicate and provide support on data management issues to other researchers. In the department,

extensive use is made of open-source code (e.g., Jive). Experimental and computational data are actively stored in the 4TU research data repository. Furthermore, 3MD researchers use resources offered by the university for open-access publishing.

10.4.3 Academic Culture

3MD strives to be an open and inclusive community of communicative and collaborative scientists. Therefore, in defining new positions, special attention was paid to creating position profiles with crucial competences. Successful candidates should not only have their own scientific niche enabling them to complement and collaborate with staff members within 3MD or other departments or faculties but should also have strong social skills. In order to improve ties within the department, bi-monthly staff meetings are held, in which one staff member pitches their background, future research/education plans and collaborative efforts. Junior staff members are involved in management processes, but connecting them in a network was, until now, not successful due to differences in expectations between management and junior staff members.

10.4.4 Human Resource Policy

As clearly stated in the self-evaluation submitted for the midterm assessment, the department is lagging behind when it comes to gender balance. Furthermore, the department is committed to improving social safety. With regard to gender balance, while ten new positions have been created since 2018, only three female candidates have been appointed, despite the department making an effort to check vacancy texts for gender-biased terms, involve colleagues in actively scouting their networks, perform bibliography searches, and involve specialised recruitment agencies. For every new vacancy, all possible measures are taken to improve the gender balance. Regarding social safety, the topic was repeatedly discussed within a wider audience (staff meetings) and in bilateral (R&D) meetings. Encouraging colleagues to speak out in a non-hierarchical setting creates a more open and safer environment. Furthermore, offering professional and trustworthy support from experts within the Faculty and TU Delft can work, but it can also be somewhat generic in nature and is not always very inviting. When serious issues with respect to social safety did occur, targeted measures were taken in the department itself. Staff members are advised to follow the “Empathic Communication” course.

10.4.5 PhD Policy and Training

PhD candidates are a large and special group of temporary colleagues who aim to finish their thesis work within four years. Unfortunately, many fail to do so. Measures have been taken in the department to improve its PhD yield by (i) applying a stricter selection procedure with a writing exercise, (ii) requiring PhD candidates to write a research plan within the first three months, (iii) holding strict go/no-go meetings, and (iv) carefully monitoring and defining the final and crucial stage of the thesis work. Furthermore, a bi-annual review is held in the department with all thesis supervisors, in which progress of the oldest cohorts of PhD candidates is discussed in a transparent, critical, and confidential setting. In addition to discussing the progress made by PhD candidates, reasons for delay, other difficulties, and best practices are discussed. The 3MD department is represented in the CEG PhD council by a dedicated PhD candidate. At the start of a PhD research project, every PhD candidate is paired with a so-called “buddy” to enable them to get off to a good start from a scientific and a social point of view.

10.5 Evidence

Table 27 lists the indicators selected to evaluate the effectiveness of the above-mentioned strategy. A brief explanation of each indicator is provided. Additionally, two case studies are presented in Appendix A.5.

The first case study “Research by Design for Future-Proofing our Cities” has been selected to show how the long-term research initiative *Deltas, Infrastructures and Mobility Initiative (DIMI)* supports the development of many research projects across the university with national and international partners. The initiative uses ‘Research by Design’ as a study approach to understand, redefine, and deal with future challenges. These include challenges that touch on climate, biodiversity, circularity, inclusiveness, mobility, the housing shortage, and limited space at multiple scales, affecting several urban systems with various stakeholders. The goal for the initiative is to present inspiring, integrated designs for the cities of the future from different angles, starting an intersectoral and interdisciplinary dialogue that helps to integrate rather than isolate research impact.

The second case study on “Safety and Damage Assessment of Buildings for Gas-extraction Induced Seismicity” has been selected for its large scientific and societal impact, and for the fact that it created a major and enriching research line within the 3MD department. Research on this topic started in 2015 and is partly ongoing. By tackling challenges in the field of building resilience, these studies have sparked new research activities in relation to the mechanics of masonry and masonry structures, which are widely present nationally and internationally. This resulted in the creation of the masonry lab with, among others, full-scale testing facilities at structural level, provided new input for education, increased national and international collaboration with researchers and stakeholders, and had a significant societal impact by helping draw up standards and providing advice on government polices (i.e. gas extraction policy, damage claim policy).

Table 27 Selected indicators for research quality and relevance to society.

	Research quality		Relevance to society
Outcomes	Highlights of projects are given to show our commitment to the scientific topics discussed in Section 10.2.2	• Open-access peer-reviewed journal and conference articles are the main means for scientific impact. Collaborative articles are highlighted.	• Media outreach shows our commitment to communication to society. • The embedding of research in CEG education and professional education (MOOC, ProfEd, PAO courses) demonstrates knowledge transfer from academia to industry.
Use		• Citation counts provide an indication of scientific impact. • PhD graduates working in academia is an indicator of the quality of our research and education.	• PhD graduates working in industry show how our department contributes to knowledge transfer from academia to practice. • Contributions to national and international guidelines and standards are indicators of societal impact, as they provide direct advice to professional practice and industrial partners.
Recognition		• Personal grants show the excellence of our researchers. • Funded projects are a token of recognition of the relevance of our research ideas. • Awards, keynote lectures, and memberships to scientific committees are a token of recognition of research quality.	• Projects funded by industrial or private-public cooperations show the societal relevance of our research. • Committees for standardisation (national and international) and advisory services provided to public authorities show our commitment to societal impact.

10.6 Accomplishments during the past six years – research quality and societal relevance

This section displays the accomplishments of the department along the lines of the selected indicators presented in Table 27. We first provide insight into research quality by discussing our projects. Secondly, we use output measures to highlight the quality of our research. Finally, we show the relevance of our research to society and the industry.

10.6.1 Research quality through projects

As described in section 10.2.2 and 10.4, our research portfolio focuses on addressing the societal challenges related to climate mitigation, climate adaptation, the energy transition, and resource depletion. For this purpose, we highlight in this section six projects to showcase our achievements with respect to the strategic aims.

Innovative geopolymers

The Geopolymer research programme, developed in the M&E section, carries out prominent research on alkali-activated/geopolymer concrete. The excellence of this programme has been recognised by five European project grants, while its innovative nature has been highlighted by scientific awards. The Wool to Loop project, which led to new smart demolition and sorting technologies combined with a novel analysis method for mineral wool waste, has received two awards from the European Commission's Innovation Radar team. The URBCON project, which demonstrates the use of self-compacting geopolymer concrete in a pedestrian bridge (see Figure 33), was nominated for the InfraTech Innovative Award. This research aims to tackle the societal challenge of resource depletion and supports our strategic aims on sustainability and the development of new innovative materials.

Figure 33 Pedestrian bridge built with self-compacting geopolymer concrete.

Waste-free and materially efficient constructions

The Parametric Structural Design and Digital Fabrication research programme run by the AM section focusses on the relationship between geometry, design, fabrication, and construction. In this programme, researchers study lightweight, flexible (formwork) construction systems that promote efficient use of material in the design and construction of complex (concrete) structures. To do so, they harness structural principles to create sound and appealing designs through form-finding techniques and generative design methods for structural optimisation, including the development of computational tools

and pipelines that reliably encode physical material behaviour during fabrication. These developments, in collaboration with ETH Zurich, have been showcased in 2022 through the KnitNervi pavilion, a full-scale temporary pavilion built using the new CNC-knitting machine acquired by the 3MD department (see Figure 34). The KnitNervi pavilion was part of the Technoscape exhibition at the MAXXI museum in Rome between October 2022 and April 2023. KnitNervi was granted the DigitalFUTURES project award in 2023. This research aims to tackle the societal challenge of resource depletion and supports our strategic aims on the development of novel construction technologies.

Figure 34 The KnitNervi pavilion, an example of a novel construction technique.

Efficient and fast multi-scale/multi-physics analyses

The Computational Mechanics research programme of the AM section revolves around the development of advanced multi-scale/multi-physics numerical models to improve our understanding of existing and new materials. The MIMIC project, funded by the “TKI Wind op Zee” programme, pioneered the development of acceleration techniques that led to a 300-fold speed increase in the runtime of complex multi-scale/multi-physics models. Based on these results, a new research line on applied machine learning was initiated as part of the NWO VIDI grant on “Multi-scale characterisation of the fracture energy for delamination” (see Figure 35) and further established in the creation of the new SLIMM-Lab as part of the Delft AI initiative. This research aims to tackle challenges related to the energy transition and resource depletion and supports our strategic aims on advanced computational techniques.

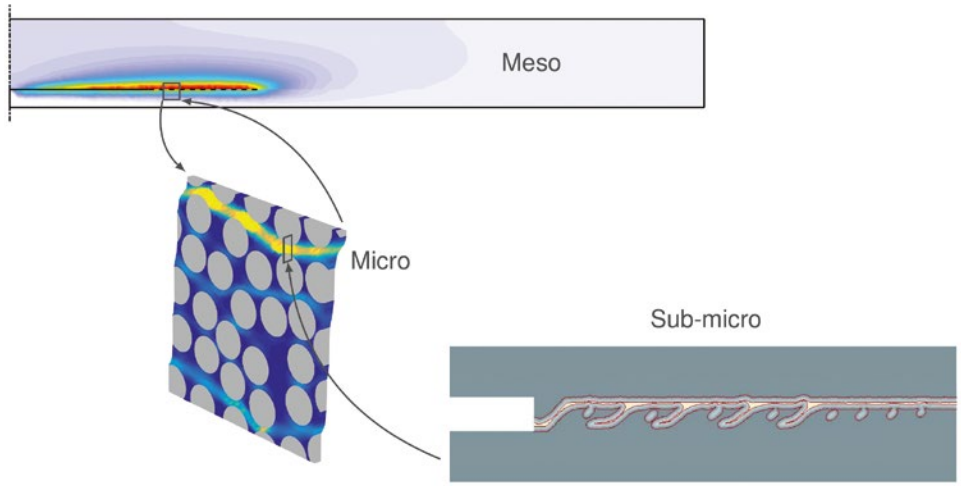


Figure 35 Advanced multi-scale model for characterisation of delamination in composites.

Sustainable 3D printing composites

The Designer Construction Materials programme spearheaded by the M&E section focusses on developing 3D printing concrete structures for construction efficiency, waste reduction, and shape optimisation. The PI responsible for the programme was recently awarded an ERC Starting Grant for the project “Auxetic Cementitious Composites by 3D printing”, which seeks to develop a completely new class of reinforced cementitious composites with a negative Poisson’s ratio, made possible by 3D printing (see Figure 36). This outstanding funding award was also made possible due to active participation in the international association RILEM, which awarded the PI a Gustavo Colonnetti Medal in 2020. This programme aims to tackle challenges related to sustainable and resilient materials and supports our strategic aims on new innovative and sustainable materials.

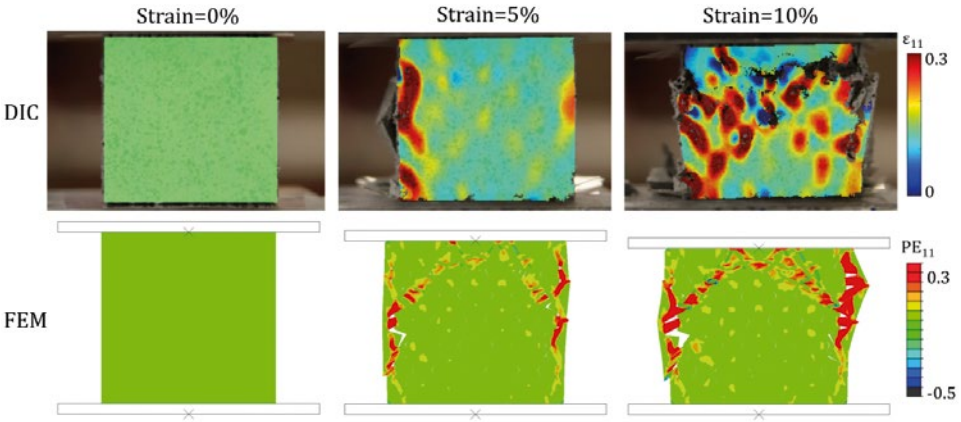


Figure 36 Advanced experimental and numerical analysis of auxetic cementitious composites for 3D printing.

Resilient masonry structures

The AM section’s Structural Mechanics research programme focusses on developing structural analysis tools for the assessment of civil engineering structures and infrastructure. In the past period, the group took the lead in tackling challenges related to resilience of Dutch masonry (infra)structure, which represents a substantial portion of dwellings, historical assets and/or key infrastructure. While the programme initially looked mainly at the safety and damage assessment of buildings for gas-extraction induced seismicity (case study 2 in Appendix A.5.2), research activities later expanded to climate adaptation of buildings on soft soil and the assessment of historical inner city quay walls. In addition to its numerical research expertise, the group set up the experimental masonry lab with facilities for full-scale structural testing. This programme aims to tackle climate adaptation challenges and supports our strategic aims on the resilience of buildings and advanced computational techniques.

Inclusive Wise Waste City

The Integral Design research programme was developed by the IDM section and focusses on designing for the future, with Inclusive Wise Waste Cities (IWWC) as one of its flagship projects. In this project, IDM collaborates with researchers from the EUR and the Netherlands Environmental Assessment Agency (PBL), and with Peking University, City University Hong Kong, and Tongji University in China. Together, the partners analyse how waste is currently collected, processed, and recycled in neighbourhoods of major Chinese and Dutch cities. They will also study the value chain for waste management in those locations, the particular roles organisations like the Upcycling Centre in Almere (see Figure 37) and social groups play in the chain and how they are affected by possible changes to the way this chain is organised. This project was kick-started and propelled through the network that had long been nurtured by the DIMI initiative (see case study 1 in Appendix A.5.1). This research tackles sustainability and circularity challenges and supports our strategic aims on creating comprehensive solutions to reduce negative environmental impact.

Figure 37 Field study of Upcycling Centre in Almere in 2021.

10.6.2 Research quality through output

Besides the individual projects, research quality can also be evaluated by examining the output of the entire research portfolio. To explain how this works, we will discuss a few tables and figures that visualise this output.

3MD's research activities have broad scientific impact by leading to publications in journals spanning from computational modelling, materials science, and structural mechanics to structural design and construction and project management. The department's scientific output has increased by 20% over the past two years compared to 2018-2020. This was achieved by means of scientific publications in peer-reviewed journals (145), conference papers (29), PhD theses (12) and a few book chapters (4). More effort was put into peer-reviewed journal publications than conference publications, due mainly due to group's growth, the increase in the number of projects, and the increased focus on journals as outlets while the COVID-19 pandemic made conferences i mpossible. Thanks to the department's policy on open-access publications (see section 10.4), open-access publications jumped from 44% in 2017 to 95% in 2022. The number of dissertations remained stable throughout the assessment period.

To investigate how our peer-reviewed publications are used, we analysed the PlumX matrix. The average number of citations per year of our peer-reviewed articles showed a 10% increase from 2019-2021 (averaging 552 citations per year) compared to 2017-2018 (averaging 486 citations per year). A decrease was observed in 2022 (208), since it usually takes some time before publications are cited. Nevertheless, a steady increase in average captures (e.g. bookmarks, code forks, favourites, readers, watchers) and social media has been observed throughout the assessment period.

Table 28 Average number of citations (Scopus) and the number of captures (PlumX) for 3MD research papers per publication year.

	2017	2018	2019	2020	2021	2022
Average number of citations (Scopus)	475	497	581	563	512	208
Captures (PlumX)	153	197	303	341	380	441

3MD staff members received various awards for excellent rewards. Besides the one mentioned in section 10.6.1, we would like to mention the New Materials Award 2018 for the Re3 Glass project, the "Talent met Toekomst" Nederlandse Bouwprijs 2017 for the Crystal Houses Façade, and the IPMA Global Young Researcher Award 2020 (International Project Management Association).

Figure 38A and B show the organisations and countries with which 3MD staff co-authored at least four publications in the period 2017-2022. This illustrates the department's close collaboration with other institutes and/or universities of technology worldwide. It shows that the sections are highly active in seeking out collaborations with a large array of international institutes, contributing to our international visibility.

Figure 38 Research network (A) companies, and national and international research units (B).

During the assessment period, the 3MD department had a healthy financial situation thanks to several research project grants. From 2020 to 2022, a period not influenced by the legacy of the former Structural Engineering department, a steady increase in both research grants and contract research can be seen. It should be noted that contract research reflects both European project funding as well as (long-term and short-term) industry funding. The sharp increase in 2022 was caused by several short-term, high-end contract research projects funded by industry (805k€). Even without this funding, overall income would have increased. Concluding, it can be said that 3MD has a healthy balance between (Dutch) research funds, European and industrial long-term research funding, reflecting both the high quality of our research and our commitment to tackling societal challenges.

Figure 39 shows the distribution of the first jobs taken by PhD graduates. A distinction is made between jobs in industry and at academic institutes The distribution is stable and balanced, showing that about half of all PhD candidates take jobs in the industry, while half continue their work in academia. This shows that the quality of our PhD research and education is appreciated by the academic world and the industry alike.

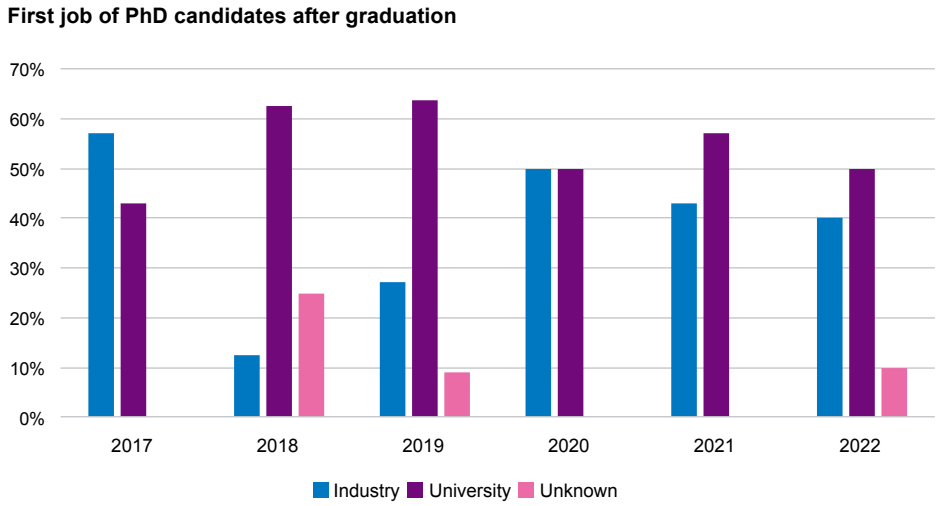


Figure 39 Overview of the first jobs of 3MD PhD graduates per year.

10.6.3 Relevance to society

Societal relevance and industrial involvement with different stakeholders of 3MD is expressed in various ways. One of these ways is tertiary funding, or funding received from industrial parties for relevant research, such as studies on the influence of sub-surface earthquakes in the Groningen region in relation to the extraction of natural gas or the development of materials with a low environmental impact such as geopolymer concrete.

Other forms of utility to society and industry have been achieved through professional publications, magazines, presentations, or by serving as invited guest speakers. Although these forms of research output dissemination are relatively rare compared to scientific peer-reviewed papers, they are still valuable vehicles for reaching a broader audience and promoting the application of research findings in real-world settings. An example is the “Research by Design” approach as promoted by the Deltas, Infrastructures and Mobility Initiative (case study 1 in Appendix A.5.1) and the way it encourages integrated design principles for policymakers and other stakeholders. DIMI publishes their results in books to disseminate the practical lessons, education, and research to a broader audience.

Teaching activities of 3MD not only focus on the BSc and MSc curriculum, but also by creating possibilities for the professional industry by providing courses for national and international professionals, such as PAO (post-academic education), MOOC (Massive

Open Online Courses) and ProfEd. Examples are the Edx ProfEd course “Fiber reinforced polymer (FRP) composites in structural engineering”, the RILEM course “Concrete Microscopy”, the TU Delft/RILEM course “Corrosion science & corrosion control for infrastructure”, the RILEM course “Multi-scale modelling for concrete”, the PAO course “Approach to foundation problems”, OpenWareCourse “Introduction to Seismic Essentials in Groningen”, and the MOOC course “Forensic Engineering”, “OpenGlassRoom” (under development).

The four patents granted to the 3MD department in the field of new materials and building practices are also a testament to the department’s state-of-the-art research, convincingly demonstrating its societal impact. The start-up GORespyre is a telling example of valorisation of novel research into real-world applications. This TU Delft spin-off focusses on the valorisation of a unique scientific cross-over between material science and biology that aims to advance nature-inclusive construction practices and a resilient built environment. The department’s use of demonstrators, such as casting prestressed girders with geopolymer concrete for bridge applications, is another effective way to bring scientific research into society and industry. 3MD is assisting the Dutch construction industry in transitioning to (i.e., low carbon footprint and circular) structures with a low environmental impact. One example is the development of alkali-activated materials, such geopolymer concretes. This development in alternative cementitious binders resulted in a remarkable 60-80% carbon footprint reduction compared to conventional products.

By showcasing the practical applications of its research, the department can demonstrate its value and relevance to a broader audience. The government’s goals for efficient resource use, adaptation to climate change, and the transition to sustainable energy pose challenges in terms of materials, structures, project execution, and cost control. To address these challenges, 3MD works closely with suppliers of materials and equipment, engineering and design firms, and construction companies. Therefore, researchers of 3MD actively participate in working groups of sector organisations (such as certifying bodies or standardisation bodies) to promote the use of research results in standards and norms. Table 29 shows the department’s involvement in committees and their influence in the building sector. Participation in national and international committees makes it possible to put into practice the latest scientific insights, whilst also providing networking opportunities. 3MD researchers are also actively involved in setting the sector’s agenda by participating in advisory boards for governmental bodies as well as in knowledge centres, such as the knowledge centre for foundation problems (Kenniscentrum Aanpak Funderingen) and regional groups like the Dutch Earthquake Engineering Association. This is effectively reflected in the case study on “Safety and damage assessment of buildings for gas-extraction induced seismicity” (see case study 2 in Appendix A.5.2), where high-quality research was promptly implemented in standards and guidelines and improved decision-making policies.

Table 29 Examples of national and international committee involvement or membership of 3MD members.

Committees	National	International
standards	NEN	CEN, ISO
guidelines	CROW-CUR, CROW-BIL	RILEM, IABSE, *fib* (Institutional + personal memberships)
other	CB’23, BRL, advisory board ministry, Bouwend Nederland*, TKI Bouw & Techniek, NETLIPSE, Stufib + Stutech committee, 4TU Bouw	

*Bouwend Nederland represents about 4300 affiliated construction and infrastructure companies

10.7 Strategy for the next six years

In this section, we report on our strategic aims for the next six years with regard to management and research. These aims are aligned with the strategy of the Faculty and the TU Delft strategic framework and are predominantly based on our mission statement formulated in section 10.2.1 for the assessment period. Strategy adaptation regarding the connecting themes will be discussed in section 10.7.2. The SWOT-analysis (Table 30) and international visit serve as the basis for the department's future strategy.

10.7.1 Future management strategy based on SWOT and international visit

Most strengths and opportunities in the SWOT analysis are connected to the research strategy and will be discussed in the next section. With respect to the future management strategy, we note that a more open-access policy for the laboratories in the Faculty will be stimulated in order to promote collaboration between departments and to improve the efficiency of technical support. The research strategy establishes a framework for recruitment of future staff members. This will further strengthen coherence and increase scientific quality of the department. The SWOT analysis lists several weaknesses pertaining to staff. First, the department will seek to improve its gender balance by permanently embedding the recruitment procedures from the recent past, namely: (i) by carefully screening profiles and vacancy texts for gender-biased terms, (ii) by making use of external networks or networks of relevant staff members in our current networks, and (iii) by using specialised external recruitment agencies. Secondly, 3MD will put a more pronounced emphasis on the future development of its staff than on past performance in the yearly R&D meetings. For our junior staff members, the R&D meeting will be more closely aligned with the academic career policy to help them meet the necessary development goals to make academic progress. For tenured staff, it is essential to emphasise academic growth and leadership during "on-track" analyses. Thirdly, it is important to better organise the involvement and embedding of junior staff members in the organisation of the department. The department plans to have young staff coached by senior staff or mentors from inside or outside the department. This has already been put into practice at KU Leuven, as we learned during the international visit. Staff members will work on their individual scientific profile, but must also be encouraged to help solve common, future societal, and scientific challenges.

Furthermore, as suggested during our visit of KU Leuven, an internal faculty/university funding scheme could be a useful tool for enhancing collaboration among staff. The profile of the department can be further improved with significant roles in national funding schemes, such as the "Groeifonds" which is already up and running. Cooperation with other universities will be further increased through the national "Sectorplan" Technical Sciences II with special attention for the Dutch KIAs ("Knowledge Innovation Agendas/ Kennis Innovatie Agenda's") and corresponding key emerging technologies. The department will also play a role in the establishment of a new national platform "Raad Civiele Techniek" (Civil Engineering Council), which aims to be instrumental in the national coordination of research activities between Dutch universities with civil engineering departments.

Table 30 SWOT analyses 3MD department.

	Strengths	Weaknesses
Internal view	• High international scientific visibility • Research focuses on multiple scales (material, structural, system) by virtue of advanced and combined experimental/computational techniques. • Coherent research agenda with scientifically and societally relevant and challenging themes and emerging technologies • Strong societal impact through research on damage assessment by seismicity in Groningen, development of low-environmental-impact building materials, involvement in standards committees and advisory roles to ministry or NGOs, etc. • Advanced laboratory facilities: 1) Microlab 2) Masonry lab 3) Delft AI/SLIMM-lab 4) supercomputer facilities DelftBlue 5) Digital Construction lab (currently under development).	• Limited involvement of junior staff in decision-making process. • Gender balance needs improvement at associate and full professor level. • Limited profile at national level for large-scale funding schemes (e.g., Groeifonds), also in cooperation with other Dutch universities (i.e., 4TU).
	Opportunities	**Threats**
External view	• A more open-access policy combined with a uniform HSE policy for all laboratories enables easier collaboration between departments under safer working conditions. • New positioning and cross-fertilization of our research activities into digital technologies in construction technology with the new Digital Construction lab in collaboration with Transport & Planning department. • Creating direct links between research activities and Sustainable Development Goals. • Defining resilience as a fourth connecting theme to promote further research collaboration in department.	• Difficulty of replacing retiring technical staff members and/or hiring future research staff (mainly PhDs/postdocs). • Political climate affects research agenda and HR policy (issues related to climate and knowledge safety). • Lack of internal funding schemes for developing fundamental and collaborative research lines.

10.7.2 Research strategy

In the coming six years, the 3MD research programme will focus on societal and scientific relevance and challenges, enabling the essential transitions as formulated in our department goals in section 10.2. The research programme is organised in a multi-scale context with challenging topics within the three groups (M&E-materials scale, AM-structures scale, IDM-systems scale) and through well-defined connecting themes/ emerging technologies.

At the materials scale, M&E will focus on designing novel materials that are greener, have lower carbon emissions, use waste streams, are smarter and are made with new production techniques, such as additive manufacturing. Open issues relate to the long-term performance and durability characteristics of these novel materials. Since design codes are usually empirical and based on experience, they cannot be used for novel materials. Therefore, numerical models have to be developed that can predict long-term behaviour of materials and structures based on their constituent ingredients and on the design/manufacturing techniques used. These numerical models will then become a basis for the development of new design codes for new materials. Monitoring mechanical behaviour and co-existing processes of these novel materials and structures with embedded sensors is also of paramount importance to measure performance and to validate the numerical models. For the more classical cementitious materials, key points of attention remain the use of green and sustainable binders, including fibre reinforcement

to improve mechanical performance. Artificial intelligence can be adopted to optimise material behaviour for a specified lifetime and for predicting long-term behaviour due to changing loading and environmental conditions because of e.g., climate change. Designing materials and structures for a specified/fixed lifetime and not for a long service life has serious advantages but requires another design approach and advanced monitoring. The primary goal of the group is to develop and valorise innovative, high-performance, low-environmental-impact building materials and socio-environmentally inclusive building strategies to improve wellbeing in the built environment.

At the structural scale, AM will focus its research efforts on the combination of multi-scale computational mechanics techniques with state-of-the-art machine learning strategies for the design and characterisation of complex, high-performance materials and structures. These materials and structures have to be developed for the energy transition and for sustainable and circular solutions. For instance, larger wind turbines require new fibre-composite materials that are lighter, stronger, fatigue- and corrosion-resistant in order to increase lifespan and reduce maintenance. Furthermore, the group will also develop robust, efficient, and reliable models for multi-scale discretisation of deformation, damage and failure processes of advanced manufactured materials (e.g. metamaterials/auxetic materials) and traditional civil engineering materials. The models will also be applied at larger-scale structures in a parametric setting. More and more attention will be paid to coupling structural safety and cyber security. Fast, nonlinear solution procedures will be integrated with structural monitoring techniques and structural design tools. In the structural design programme of AM, safe, sustainable and smart strategies for the design, construction and re-use of civil engineering structures and infrastructure will be developed with a focus on e.g., structural glass, bio-based materials, and parametric structural design and digital fabrication. Furthermore, there will be more focus on robotics in structural engineering and circular design of structures. Regarding the energy transition and climate adaptation, the group is expanding its research activities to study the structural response to seismic ground movements in an integrated manner, including the use of artificial intelligence to account for uncertainty and different scenarios. For the management of historical urban infrastructures, such as quay walls, buildings, and bridges, proper assessment tools for preservation need to be developed together with new sustainable materials and construction techniques for efficient renovation.

At the systems scale, resilience is an integral and important theme for IDM, with a focus on integral asset planning, simulation models, service logistics techniques, including the development of state-of-the-art asset information and decision support systems technologies. Circularity will also be a key topic, with the main focus points being the market potency and financial feasibility of sustainable innovations in the construction and infrastructure sector, spanning various infrastructure assets, such as wind parks, civil structures, and buildings, as well as the component (reusable materials) and material (bio-concrete and potentially composites) levels. Digitalisation will be an increasingly important topic apart from a technological perspective, focusing on both the human and social capital in civil engineering projects. Finally, IDM's research will focus on transdisciplinary design and project management, i.e., collaborative design with key players in the design process in order to realise joint and effective strategies that translate societal challenges into interdisciplinary designs for new infrastructure. Effective and collaborative design strategies are needed for the upcoming replacement of locks and flood defences, railway stations, ports, and airports from the perspective of climate change, the energy transition, the circular economy, and ongoing urbanisation. IDM will work on these topics from a socio-technical perspective in order to better enable this transition by focusing on resilience, sustainability, and people. The expertise in the department regarding decision support systems, digital technologies and management of integration is therefore crucial.

With the appointment of new staff members, the expertise in digital engineering has significantly increased on topics such as building information modelling (BIM), knowledge graphs (KG), visualisation technologies (VR/AR/XR), Internet of Things (IoT), machine learning, and digital twinning.

The topics within the three sections are interconnected by the three themes and emerging technologies, i.e. (i) multi-scale design, starting at the manufactured/architected material scale (M&E) to computational multi-scale modelling and optimisation at the structural scale (AM) to transdisciplinary design at the systems scale (IDM), (ii) circularity/ sustainability, spanning the development of circular/sustainable building materials (M&E) and structures (AM) to the analysis of total cost for society (IDM) and (iii) machine learning/digitalisation, starting with the development of AI techniques for material health monitoring (M&E), the SLIMM lab's activities regarding machine learning, novel digital fabrication (knitting techniques and robotics) and the resilience of masonry structures (AM), and digital engineering coupled to project management and integral design at the systems scale (IDM). The newly introduced Digital Construction laboratory will act as an additional scientific driver for the connecting themes and technologies. Resilience, as mentioned in the overall aims of the department in section 10.2.1, is seen as a more integrated activity in the coming six years, which is why we see it as our fourth connecting theme/technology (see Figure 40). Designing resilient structures and systems that can withstand climate change or natural and man-made hazards is of the utmost importance. For instance, all three sections of the department are involved in developing new concepts for e.g., damage assessment and building repair, corrosion protection of offshore and onshore structures, and adaptive strategies needed to consider cost-effectiveness.
To emphasise the importance of resilience, two Delft Technology Fellowship positions have been created for female candidates: one on the "corrosion of civil engineering materials and structures" and one on "fire safety of civil engineering materials and structures", which will help to improve the gender balance of 3MD as well. Furthermore, in TU Delft's Countours2030 growth strategy, "Resilient Living Environment" is also mentioned as one of the three main innovation themes in research and education.

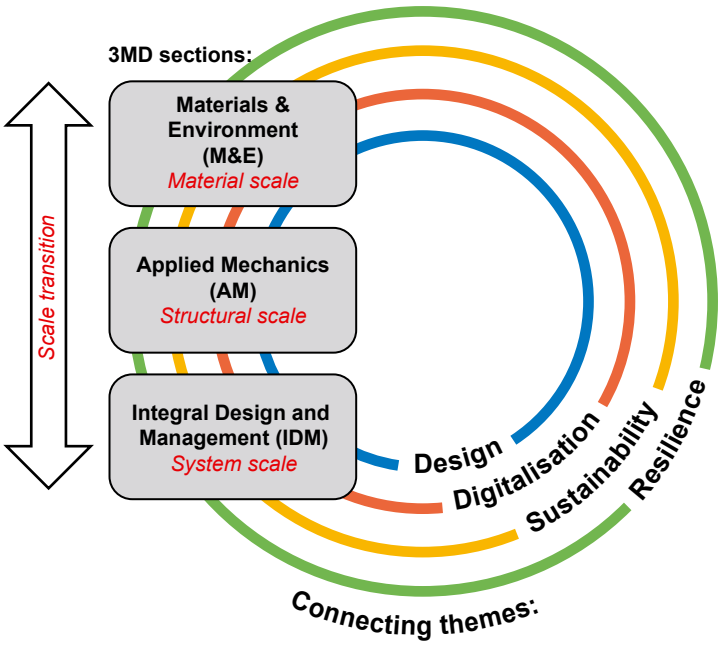


Figure 40 Department structure, sections and connecting multi-scale themes and technologies for 2023-2028.

Appendix A
Case studies

A.1.1 ES Case study 1:
Concrete to Cement & Aggregates (C2CA) technology for circular concrete

Supply for concrete jeopardised

Concrete is indispensable for the construction of bridges and housing. The Netherlands is in the throes of a housing crisis and is crying out for more houses, while its infrastructure is in need of renovation. Moreover, high-grade concrete is an essential material for the design of future infrastructure (such as the hyperloop). Concrete production requires massive resource extraction on a global scale, raising environmental, social, and economic concerns. With the input materials for traditional concrete production (natural sand, blast furnace slag and fly ash produced by coal power plants) expected to run in short supply, the department of Engineering Structures is working on turning concrete waste into secondary raw materials to produce high-grade circular concrete.

Circular concrete to combat resource shortage

Funded by the European Commission, the Resources and Recycling section developed a suite of technologies (C2CA Technologies) to process concrete waste from End-of-Life buildings and infrastructure into new raw materials for high-grade concrete production. These technologies led to prototypes that were demonstrated at the Hoorn recycling site in collaboration with Dutch construction company Strukton. The spin-out C2CA Technology received the EU Innovation Radar award for most sustainable technology and 1.5m€ in funding from investment company Chrysalix.

Technological innovations to optimise reuse

The transition to a share of 30% circular concrete in Europe by 2030 requires major innovations, including regulatory frameworks, digitisation, and physical and chemical processing technologies.

Technological Innovations range from the inventory and smart dismantling of End-of-Life buildings to the production and quality control of high-grade sand, gravel and binders from real-life waste concrete. The C2CA series of technologies aims to improve the last part of this chain by separating cement-rich fine fractions from waste concrete. Some technologies focus on finding the perfect source for the new generation of concrete with the right mechanical and engineering properties. Other C2CA technologies aim to develop a tracking system based on radio-frequency tags to monitor product flows and quality to support automated production. Realising a sustainable solution based on the circular economy is now a step closer, eliminating polluting production processes, reducing transport and greenhouse gas emissions, and converting concrete waste into a new concrete product. This transformation will contribute to achieving the European target of facilitating the large-scale throughput of green and recycled construction materials.

C2CA technologies enter the market

The C2CA technologies show that producing high-grade circular concrete with a fully transparent, watertight and digital quality guarantee from relatively clean End-of-Life concrete is economically feasible. The investment by Chrysalix means that the first C2CA technology sales will be made in 2023-2024, forming the fourth spin-out of Resources & Recycling selling the group's patented technologies as a commercial company.

A.1.2 ES Case study 2:
Gentle Driving of Piles (GDP) Technology

Offshore wind with less disturbance to marine life

Offshore wind turbines are key to the energy transition in the Netherlands and the rest of the world. The large piles that support these structures at sea are usually driven into the seabed with an impact hammer, disturbing marine life to an unacceptable extent. The piling of such huge piles, which measure approximately 10m in diameter and are more than 100m long, emits immense noise and vibrations, which need to be reduced by all means. To achieve this, the department of Engineering Structures (ES) invented and patented a new piling method, which is currently being developed in a series of projects, significantly co-funded by more than fifteen industry partners.

Patented technology supported by international alliance

The method, called Gentle Driving of Piles (GDP), utilises high-frequency torsional and low-frequency vertical vibrations that emit low sound levels and enable superior drivability. In developing GDP, ES academics face multiple challenges, which they combat in close collaboration with the Hydraulic Engineering department.

GDP is developed with funding and support from the Netherlands Enterprise Agency (RVO - Rijksdienst voor Ondernemend Nederland) and the international GROW consortium that encompasses twenty leading and committed international partners that cooperate closely to conduct joint research in Offshore Wind.

The GDP journey started in 2018 with a 4m€ project. After several follow-up projects (i.e. the 6m€ SIMOX), a GDP 2.0 project is due to start soon aiming at demonstrating the technology offshore at a 50% scale. The goal is to get the technology market-ready by 2027 by means of mutually beneficial cooperation between the ES department, the GROW consortium and recently established Vibrotwist spin-off company.

Scientific foundations of the GDP technology are disseminated in several scientific (keynote) presentations and prize-winning journal publications. Researchers have also given interviews to reach the general public, for example to Dutch broadcaster NTR.

Successful contribution to the energy transition

The EU ambition to future proof the renewable energy requirements is enormous. Specifically, the Netherlands aims to a achieve a 21 GW energy production from wind farms alone by 2030/2031. In this context, the GDP projects play a vital role in reducing immense noise and vibration levels during the installation process of the wind farms' support structures. At the same time, it is expected that the GDP technology will accelerate the installation process, saving time and allowing a larger number of installations inevitably needed to achieve the desired energy target.

A.2.1 HE Case study 1:
Fact finding for the 2021 summer floods

Information gathering directly after floods

In July 2021, the south of Limburg and neighbouring countries were hit by severe flooding, sparked by unprecedented precipitation and river discharge. In the days following this disaster, TU Delft set up the Floods Fact-finding Taskforce with the aim of collecting as much factual information about these exceptional summer floods as possible. The taskforce's efforts have boosted research and have made it possible to respond to societal demands to develop a comprehensive, fact-based plans to mitigate damage in the future.

The department of Hydraulic Engineering (HE) formed a consortium of nine knowledge partners (Universities of Utrecht, Twente, Amsterdam and Wageningen, KNMI, Deltares, Erasmus MC and HKV) under the umbrella of the Expertise Netwerk Waterveiligheid (ENW) and worked in full cooperation with Rijkswaterstaat and Waterschap Limburg to gather as much information and data as possible.

Insights form a basis for evaluation and improvement

Only six weeks after the floods, on 10 September 2021, the Fact-finding Report was presented in an online webinar with over 900 participants from the government, industry and the general public (citizens and NGO's). The findings of the Taskforce are published in a special issue of the Journal of Coastal and Riverine Flood Management and have been published as datasets in the 4TU Research Data Portal.

Measurement data showed that the peak discharge of the Meuse River and several of its tributaries reached record levels. The study also provided insight into the performance of infrastructure, showing that the primary flood defences along the Meuse effectively withstood the exceptionally high loads well, but that incidents and local height deficiencies did occur in some places and specific temporary measures were deployed on a large scale.

The estimated total damage amounted to 500-600 million Euro. To gain insight into the health impact, the HE team collaborated with Erasmus MC as part of the Pandemic and Disaster Preparedness Centre (PDPC). It was shown that COVID transmission was higher in the most flooded areas than elsewhere. The findings of the Taskforce are now being used to evaluate the system and identify technical, spatial and organisational improvements.

This fact-finding initiative was preceded by similar but smaller responses to flooding disasters across the globe in recent decades, such as in the USA (Katrina), Germany and Thailand. As a follow-up to this case study, TU Delft is participating in a large EU-funded research project (the Interreg project EMFloodResilience (2022 - 2023)) along with 10 other international partners, led by Waterschap Limburg.

Enhancing preparedness for future flood events

With the fact-finding mission and the extended EU-funded project, TU Delft can become a leading international centre of expertise on flood risk management, which will become a field of growing importance due to climate change. Thanks to the close cooperation with world-class partners, the department can contribute to solving urgent problems by delivering new insights, solutions and measures.

A.2.2 HE Case study 2:
SALTISolutions
(Salt Intrusion through Urbanising Deltas: Solutions)

Salt intrusion threatens freshwater availability

Deltas are home to billions of people all over the world, sustaining important and diverse ecosystems. They connect our oceans to inland rivers and serve as heavily modified, deepened waterways for shipping, construction of new and larger harbour facilities, land reclamation and diversion of river flows. An unwanted side-effect of these urbanising deltas is that seawater intrudes deeper inland, which is exacerbated by the rising sea levels and altered seasonal patterns of rainfall and river discharge caused by climate change. During recent droughts in the Netherlands and other low-lying Delta countries, salt intrusion threatened the supply of drinking water and freshwater for agricultural and industrial uses. The escalating problem of salt intrusion is a threat for freshwater availability in deltas worldwide.

The Virtual Delta

The SALTISolutions research programme aims to empower hydraulic engineers and provide insights for decision making for a liveable future Delta. This EUR 6.68 million, six-year, NWO-funded Perspective Research Programme is led by Prof. Julie Pietrzak (the department of Hydraulic Engineering (HE)) and unites leading national experts from the universities of Eindhoven, Wageningen, Utrecht, Twente and Delft. Together with our partners Rijkswaterstaat, Deltares, Dutch consultancy firms, water boards, port authorities and dredging companies, SALTISolutions will produce 'VirtualDelta', a digital twin of the Rhine-Meuse Delta. The programme is curiosity driven and application inspired, the latter feeding off the former.

PhD candidate Tess Wegman on a field campaign in the Rhine-Meuse Delta.

Intended breakthroughs range from novel parameterisations of turbulent mixing processes and complex river junctions to new insights into coupled delta-ocean interactions, including under extreme climate change. The understanding of freshwater in the Dutch and other deltas will help to pioneer new nature-based solutions and mitigation strategies. We will use what we learn in SALTISolutions to train a new generation of Hydraulic Engineers, who are confident in the new fields of digital twins and Artificial Intelligence and have a deep understanding of physical processes and mitigation and adaptation methodologies.

Unique field campaign provides crucial knowledge

In 2022, an important step has been taken towards the digital twin with the deployment of a major field campaign around the mouth of and within the Rotterdam Waterway. The campaign was initially planned for seven weeks, but due to the unprecedented drought, it was continued for 17 weeks. It led to the collection of a unique data set of temperature, salinity, currents, and turbulence, that will provide crucial knowledge to advance our physical understanding of the system and how to model and manage it.

Better prepare society for future salt intrusion events

SALTISolutions paves the way for salt intrusion mitigation, adaptation and the design of future-proof deltas. Developing long-term scenarios is crucial for current policy decisions and climate-proofing future infrastructure developments. SALTISolutions is fully in line with TU Delft's ambitions to be a national and international leader in the development of salt intrusion management and is supported by many highly ranked international universities and research institutes, such as the University of Washington and Woods Hole Oceanographic Institute from the USA; the University of British Columbia from Canada; the University of Cambridge and the National Oceanography Centre from the UK; the University of Sun Yat-sen from China; and the University of Trieste and the Leibniz Institute for Baltic Sea Research from Europe. It is a field of utmost importance given the urgency of climate change and the severity of recent droughts in 2022, and the ongoing extreme weather experienced by many in 2023. HE engineers manifestly have a major role to play in designing 'future proof' deltas.

A.3.1 TP Case study 1:
Transitioning to low-car cities

Citizens reclaim public space

Cities across the world are transforming in order to become more pleasant places to live in, driven by people's wishes to reclaim public space and promote walking and cycling. The Netherlands has long been a pioneer in fostering a cycling culture, resulting in positive impacts on mobility costs, safety, and equality. In the 21st century, the country is facing another pivotal moment, prioritising active modes of transportation (like walking and cycling) and aiming to create car-free cities. The department of Transport & Planning (T&P) has played a leading role in researching and supporting the transition to low-car urban regions.

Realising smart mobility hubs in Amsterdam and beyond

Amsterdam, which wishes to ban cars by 2030, is a leading example. Several research projects led by the T&P department have sought to provide the puzzle pieces needed to reach that goal. To support the mobility needs of citizens, the T&P lab for Electric and Automated Transport (led by Correia and Martínez) has investigated the introduction of the concept of shared mobility hub, developing smart hubs and e-hubs that boast a combination of electric cars, electric bikes, and electric cargo bikes. Valuable insights have been gained about planning, facilitating, and responding to traveller behaviour. A direct impact on the uptake of shared mobility has since been observed. Tools to plan and deploy these hubs are now available for other cities in the Netherlands and around the world.

Pleasant and safe pedestrian spaces

The T&P department has developed unique knowledge of the challenges and issues that cyclists and pedestrians face. Our Active Mode Lab, led by Duives, studies the choices and behaviour of pedestrians and cyclists. In recent years, the Active Mode Lab performed multiple studies into the route choice behaviour of these road users to identify elements of the urban environment that invite active mode users.

City center of Amsterdam with − a mix of − active modes and public transport.

The EIT-KIC-funded project CityFlows is an example of a project to improve the liveability of crowded pedestrian spaces by providing decision support tools to manage pedestrian flows. In another project, Artificial Intelligence technology was used to provide forecasts for managing crowds. The police now use this knowledge to plan their interventions and increase safety, which shows the direct impact of this research.

Mobility solutions in future situations

The transition to low-car urban regions has only just begun. Soon, the T&P department will start developing digital twins of low-car urban areas as part of the NWO Perspectief- funded XCARCITY project (led by Van Arem and Snelder). These virtual models will shed more light on the effects of different mobility solutions and be used to test various scenarios and interventions for addressing specific problems in the cities of Almere, Amsterdam, and Rotterdam. In the coming years, the representation of mobility in the virtual world will take off and produce a wealth of invaluable simulated data, enabling us to investigate situations that do not currently exist and risks that we do not yet understand.

A.3.2 TP Case study 2:
Mobility management during a pandemic crisis

The pandemic and its effects on mobility patterns

The COVID-19 pandemic resulted in travel restrictions. Lockdowns and an increase in working from home drove people away from public transport. In the end, the pandemic has had a significant impact on entire transport and mobility systems. To address the resulting challenges, the department of Transport & Planning (T&P) has developed methods, tools, and empirical findings to support decision-making in mobility management. Investigating the relationship between mobility patterns, shifts in travel preferences and how viruses spread could help to improve traffic and mobility management during pandemics.

Shifts in travel preferences

The shifted travel preferences and changed behaviour appeared to be persistent, as indicated by extensive analysis performed by the T&P department. This analysis was part of the NS panel survey on COVID-19, in which train travellers were asked about their preferences and considerations. Urgent policy questions about mobility during the COVID pandemic were also addressed in the MOCOLODO project. The T&P department's overview papers on adapting transport schedules helped the public transport sector deal with the consequences of the crisis.

Insights to limit virus transmission

The SamenSlimOpen project developed quantitative models and software to identify the risk of spreading COVID-19 within indoor environments, such as in public transport. The conclusions were presented to policymakers and relevant interest groups to provide insight into the impact of crowd management protocols, access policies for (non-)vaccinated people (2G/2G+/3G), and ventilation on transmission risks.

Transport & Planning provided technology to measure infection risk enabling students to study in the library of TU Delft during the pandemic.

At the national level, the T&P department led a consortium tasked with designing and implementing technology to keep schools and universities open during the pandemic. This led to the development of a monitoring system and a dashboard to track and visualise unsafe interactions between students, staff, and 'bubbles' (groups of people in which social distancing was not possible because of educational activities). This technology helped design optimal circulation plans and quarantine strategies.

Predicting traffic flows

As a result of these and other research efforts, we now have unique datasets on the changes in travel demand and attitudes spanning the entire duration of the COVID-19 pandemic in the Netherlands. These data can be used to create models that predict behavioural changes.

A.4.1 WM Case study 1:
Circularity in the urban water cycle

Water scarcity calls for an improved urban water system

By 2025, two thirds of the world population could be affected by water scarcity and extreme water stress, posing a serious threat to the world's population. Especially in rapidly urbanizing areas, the implementation of sanitation and potable water infrastructure is not keeping up with population growth. Historically, our urban water systems were designed to deliver potable water to the city and subsequently discharge it into open water bodies. However, our natural water resources have come under serious risk from (over)abstraction of source water from the surrounding environment (e.g. groundwater) and the discharge of polluted water. In a circular water system, we could reduce the city's water footprint by recovering water for reuse, as well as recovering the potential resources it carries, such as nutrients and heat. Recovery of such resources can contribute to achieving circular economies amidst the current energy and nitrogen crises as well as accelerating implementation of sewage water treatment globally. The department of Water Management (WM) develops new technologies that can drive the recovery of water, nutrients and energy in cities.

Making the most of water usage

An entirely new method developed at WM generates electricity by fuelling a solid oxide fuel cell with ammonia recovered from wastewater via vacuum membrane stripping. Removal of total ammoniacal nitrogen (TAN) is important to prevent environmental damage, but the treatment is very energy intensive. With this recently patented technology, the outcome of PhD research by Niels van Linden (see photo), TU Delft start-up MEZT is currently running a pilot with manure to reduce nitrogen emissions.

Another, completely different innovation is thermal energy recovery from drinking water distribution networks. This technology was developed by PhD candidate Jawairia Ahmad and has now been implemented by Waternet, Amsterdam's drinking water supply company. Dr. Ahmad investigated the potential consequences of elevated water temperatures after energy recovery for the microbial safety of tap water (e.g. *Legionella* growth).

The research on circularity also extends beyond the Netherlands, as illustrated by the WM-led LOTUS^{HR} project. In this project, funded by NWO and the Indian department of Biotechnology, over ten PhD candidates work on water challenges in Indian megacities. In New Delhi, a living lab was constructed on the banks of the Barapullah drain with partner university IIT-Delhi. This water body is a huge open sewer that eventually feeds into the river Ganges, putting the health of millions at risk. In this living lab, visited in 2019 by King Willem-Alexander and Queen Maxima, novel technologies for the safe and socially accepted reuse of water can be tested.

A transition to a circular water system

The WM department develops state-of-the-art technology to foster the transition to a circular water and resources system. Research is typically conducted in close collaboration with stakeholders, including water boards, drinking water companies and tech companies. These collaborations have been shown to accelerate new technology adoption in the water sector, as well as allowing WM to tap into industry funding and infrastructure. As such, WM is able to translate fundamental research that advances scientific understanding into technological solutions that address societal challenges.

A.4.2 WM Case study 2:
Rainfall mapping in Sub-Saharan Africa

African agriculture is mainly rain fed

In Sub-Saharan Africa, over 95% of agriculture is not irrigated, but relies solely on rainfall. Accurate and timely rainfall mapping is urgently needed to develop climate services for (smallholder) farmers and for flood early warning systems. By establishing a sufficiently dense network of meteorological stations, ground measurements and satellite-based geo-data could be used to build reliable weather models for sub–Saharan Africa.

Make farmers more resilient

The WM department has led several initiatives in this area, including the TAHMO initiative, which has established a network of about 650 low-cost weather stations (see photo) across East, West and Southern Africa. These stations measure currently unavailable geo-information on weather, water, and climate for locations in sub-Saharan Africa with additional innovative in-situ sensors. This TAHMO network delivers services developed through the H2020 TWIGA project, including localised, timely weather forecasts, flood early warning and crop insurance and heat stress indices for livestock. These services have helped to increase the resilience of African farmers and citizens by enabling climate-smart decision-making on farm operations and insurance. The follow-on Horizon Europe TEMBO project is currently building cost-effective innovative sensors for the TAHMO network that can be financed by co-developing large socio-economic value in the fields of geo-hazards, reservoir management, and agricultural information services.

Insights into rainfall for ten African countries

At the recent UN 2023 Water Conference, WM, together with TAHMO, announced its commitment to install sufficient weather stations to cover at least ten Sub-Saharan African countries by 2030. This is an exciting and ambitious target, which the department hopes to achieve together with the Kenyan Meteorological Society, Masinde Muliro University of Science and Technology (MMUST) and Jomo Kenyatta University of Agriculture and Technology (JKUAT).

Global water challenges

This WM research line illustrates the department's long-term commitment to impact-driven research that addresses key international development challenges related to water. The department leads Water for Impact, a campus-wide TU Delft Global Initiative programme that connects water research with local and global impact by bringing together academic institutions, governments, NGOs and private sector organisations to co-create innovative solutions to global water challenges. Water for Impact aims to work on water-related challenges such as hygiene, sanitation, pollution, flooding and availability for drinking and irrigation purposes and is active in an estimated 28 project countries, including Ghana, Mozambique, Zambia, Uganda, Brazil, Costa Rica, Indonesia, Bangladesh, Nepal and India.

A.5.1 3MD Case study 1:
Research by Design for future proofing our cities

Cities face a multitude of societal issues and system transitions

The cities we live in, are not future proof. Several factors challenge the liveability, such as climate, biodiversity, circularity, inclusiveness and mobility. The population is expanding, housing is in short supply, and we also have to deal with heat stress, drought, and traffic jams. To deal with these widely divergent challenges, TU Delft has started to redefine them with an interdisciplinary approach. The Deltas, Infrastructures and Mobility Initiative (DIMI) uses Research by Design as a method for exploring tangible futures for problematic or favourable locations within the present built environment, presenting inspirational integrated designs for cities challenged by a multitude of social issues and system transitions from different angles by starting an intersectoral dialogue. This offers policy makers, city management and other stakeholders the awareness of the potential power of integrated design for the contextual interpretation and (re)definition of societal challenges and its relevant aspects for an array of locations. Integration prevents that related problems are solved in isolation, causing sub-optimization.

Research by design as process and instrument to explore city's future

Research by Design is both a collaborative and interdisciplinary learning process as well the imagination how an urban location could look like after 20 to 30 years. The process includes analysis by joint fact-finding and lead to a shared vision, principles and design strategies. The application of these by co-creation results in an integrated and tangible design which will be reviewed by involved stakeholders on basis of criteria related to spatial advantage, quality of the living environment, its future proof and feasibility for implementation. Designs can be made for different time spans, from the long term for futuristic explorations, and then backtracking to the current situation, to the short term by providing steppingstones in the process of preferred transitions.

DIMI publishes their results in accessible and reflective books and/or essays to disseminate the practical lessons, education and research to a broader audience. This integration of tangible results and its reflection from a scientific perspective clarify the context and meaning of the results for practice. An editorial board assess plausibility of every book publication.

This available source of knowledge proves to be of considerable value for the recently established programme "Redesigning Deltas" of the convergence program Resilient Delta. The resulting designs have been creating impressive impact in the sector. It is an accepted methodology for spatial exploration of complex and uncertain developments by the Minister of Spatial planning and Housing (Ministry BZK) and the Topsector Creative Industry. Furthermore, the Board of State advisors (CRA) apply the method for advising ministries. DIMI played an important role in these developments.
The teams working on these projects are extremely diverse. For the project 'City of the Future,' the five biggest Dutch cities contributed, together with ten design teams from the sector (approximately seventy partner organisations) and many academics. Also, eighty civil engineering students of the first-year course on Integrated Design, worked in eight separate design teams on a specific case of City of the Future. The cross-pollination between departments and between faculties is also abundant and the design studies benefit from the broader relations, in terms of the joint 4TU Master programme on Construction Management and Engineering. The collaboration in teaching and supervision of master and bachelor students, helps to foster a collaborative culture and reach out for joint projects through DIMI as an intermediate platform for intersectoral collaboration, interdisciplinary learning and knowledge production and its dissemination to practitioners, students and scientists.

Strengthen disciplinary and sectorial networks and collaboration

The effect of network initiatives like DIMI gives the department of Materials, Mechanics, Management & Design (3MD) a strong position in the university. In order to collaborate and capitalise on these further targeted investments in new staff on connecting themes may use the DIMI network to engage strong mono disciplines in the 3MD department. It can catalyse the unification of the sections within 3MD to continue in this direction and build sustainable relations in the faculty, in and outside the university. The several projects co-initiated by DIMI since 2014, has also led to a network with sectorial stakeholders. Some of them were invited for guest-lectures and others joined in a consortium developing research proposals. Some of the projects have also led to other projects which solidifies this network as a relevant link with practice.

A.5.2 3MD Case study 2:
Safety and damage assessment of buildings for gas-extraction induced seismicity

Assessing buildings after induced earthquakes

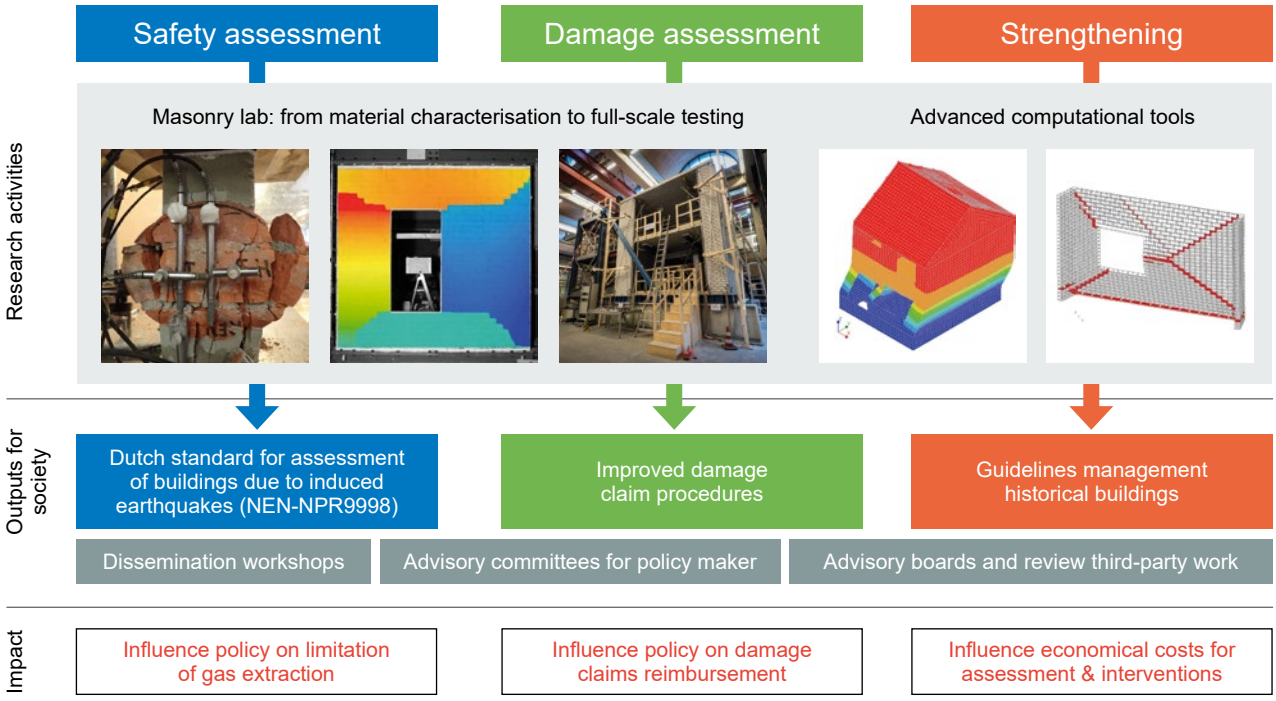
Earthquakes caused by gas extraction in the built environment have been a major socio-economic challenge for the Netherlands in the past years. The main concerns are safety (collapse states) and cracking in vulnerable masonry houses (lower damage states). Given the absence of natural tectonic seismicity (earthquakes), the Netherlands had never been prepared for seismic design and evaluation of damage claims, prompting the need for research programmes involving national and international experts.

The Structural Mechanics group within the department of Materials, Mechanics, Management & Design (3MD) is a leading contributor to the research programme supporting the assessment and strengthening of masonry buildings in response to induced seismicity (website). Initially (2015), this programme was funded by the Nederlandse Aardolie Maatschappij (NAM), the company extracting the gas in the region. The results of this original research provided the basis for starting several other projects funded by the Ministry of Economic Affairs and Climate Policy (EZK), the Institute for Mining Damage Groningen (IMG), the Ministry of Cultural Heritage (RCE), the national coordinator for Groningen (NCG) and the Top Consortium for Knowledge and Innovation (TKI). The research programme has access to approximately EUR 10 million in funding.

Supporting governmental policy

The research is organised along three pillars: developing a safety assessment strategy, distinguishing damage caused by earthquakes from damage caused by other factors (e.g. settlement, shrinkage), and developing innovative repair and strengthening methods.

The programme developed high-quality research outputs that have met with international acclaim and resulted in new research lines related to mechanics of masonry and masonry structures, the foundation of the new Masonry lab (as part of the Macromechanical Laboratory) and new educational content for both BSc and MSc programmes as well as for professionals (OpenCourseWare on “Introduction to Seismic Essentials in Groningen”). The successes strengthened internal collaboration within 3MD, with the department of Engineering Structures, and with national and seismic-specialised international partners. The scientific impact lies in validation of tiered assessment approaches against multi-scale



Outlook of research activities, output and impact for society of the research on safety and damage assessment of buildings due to gas-extraction induced seismicity.

testing (material, wall and building scale) and improved constitutive and computational models (e.g. a new masonry model in DIANA FEM software, extensive materials characterisation, improved sequentially linear and nonlinear procedures).

The programme generated major societal impact, contributing to the new Dutch standard for seismic safety assessment (NPR9998), to a new and fairer damage claim procedure, and providing guidelines for preserving historical heritage. In the process, the programme also influenced the country's policy on gas extraction and reimbursement of damage claims and provided input for a faster and more reliable assessment strategy to reduce associated costs. To generate this impact, researchers in the group actively participated in standardisation committees, advisory boards, and served as reviewers for third-party work.

Structural resilience and sustainability

The newly established research lines are expected to expand and touch on structural resilience and sustainability in the future. This further supports the selection of resilience as 3MD's new connecting theme for the next six years. The programme already managed to attract new NWA and TNO funding for research on climate-induced damage to buildings and AMS funding on resilience of urban infrastructures, both of which are expected to continue in the years to come.

Appendix B

Compulsory tables

B.1 Input of research staff[43]

Table 31 Input of research staff. Tables are based on the following assumptions: (i) only salaried staff members are included, with the exception of PhD candidates, (ii) headcount is adjusted for availability of staff member, (iii) FTE is adjusted for availability of staff member and contribution to research (40% for scientific staff and 80% for Researchers and PhD candidates), (iv) Researchers are selected based on the first UFO-profile 'Onderzoeker'.

All Civil Engineering Departments

	2017		2018		2019		2020		2021		2022	
Research unit	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	107	37,7	109	38,5	115	39,7	120	41,5	138	48,3	147	51,1
Assistant professor	50	19,1	48	18,5	50	18,0	52	19,1	65	24,1	65	23,8
Associate professor	24	7,9	27	8,7	31	10,4	32	11,3	35	12,6	41	14,5
Full professor	32	10,7	34	11,3	34	11,3	35	11,2	37	11,6	41	12,7
Researchers (2)	107	73,7	112	75,2	108	73,5	125	86,2	107	72,2	109	75,1
PhD candidates (3)	450	293,2	462	299,5	457	289,1	451	289,0	444	276,0	446	280,3
Total Research staff (1+2+3)	**664**	**404,6**	**682**	**413,1**	**680**	**402,3**	**695**	**416,8**	**689**	**396,4**	**702**	**406,5**
Support staff (research)	27	24,7	28	25,1	31	27,8	34	30,8	37	32,5	34	29,7
Total staff	**691**	**429,3**	**710**	**438,2**	**711**	**430,1**	**729**	**447,5**	**726**	**429,0**	**735**	**436,2**

Structural Engineering (StrE)*

	2017		2018		2019		2020		2021		2022	
Research unit	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	38	13,2	-	-	-	-	-	-	-	-	-	-
Assistant professor	16	6,4	-	-	-	-	-	-	-	-	-	-
Associate professor	10	3,0	-	-	-	-	-	-	-	-	-	-
Full professor	11	3,9	-	-	-	-	-	-	-	-	-	-
Researchers (2)	49	34,0	-	-	-	-	-	-	-	-	-	-
PhD candidates (3)	133	87,9	-	-	-	-	-	-	-	-	-	-
Total Research staff (1+2+3)	**220**	**135,1**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**
Support staff (research)	14	13,6	-	-	-	-	-	-	-	-	-	-
Total staff	**233**	**148,7**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-**

* Structural Engineering (StrE) has been split up into two separate departments, Engineering Structures (ES) and Materials, Mechanics, Management & Design (3MD).

Engineering Structures (ES)

	2017		2018		2019		2020		2021		2022	
Research unit	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	-	-	21	6,6	21	6,4	22	6,7	28	9,2	30	10,0
Assistant professor	-	-	8	3,2	10	3,4	11	3,7	16	5,9	16	5,8
Associate professor	-	-	5	1,3	5	1,1	4	1,1	4	1,3	6	2,1
Full professor	-	-	7	2,1	7	1,9	7	1,8	8	2,1	8	2,1
Researchers (2)	-	-	24	17,2	20	14,7	27	20,0	22	15,8	32	24,0
PhD candidates (3)	-	-	50	33,8	48	32,4	51	37,5	56	40,6	60	43,7
Total Research staff (1+2+3)	**-**	**-**	**94**	**57,6**	**90**	**53,6**	**99**	**64,2**	**106**	**65,6**	**123**	**77,7**
Support staff (research)	-	-	9	9,0	10	10,1	11	11,0	13	13,1	13	11,7
Total staff	**-**	**-**	**103**	**66,6**	**100**	**63,6**	**110**	**75,1**	**119**	**78,7**	**135**	**89,4**

[43] According to Strategy Evaluation Protocol compulsory table E2

Hydraulic Engineering (HE)

	2017		2018		2019		2020		2021		2022	
Research unit	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	26	8,8	28	9,1	28	8,9	30	9,8	37	11,8	39	12,0
Assistant professor	13	5,0	12	4,6	11	3,9	13	4,6	17	6,3	16	5,7
Associate professor	4	1,2	6	1,7	7	2,2	8	2,5	9	2,7	11	3,3
Full professor	9	2,7	10	2,8	10	2,8	10	2,8	11	2,8	12	3,0
Researchers (2)	21	12,9	21	13,2	21	13,0	25	16,4	26	16,5	25	15,4
PhD candidates (3)	116	78,1	115	76,1	117	72,3	113	70,6	111	65,7	108	64,2
Total Research staff (1+2+3)	**163**	**99,9**	**163**	**98,4**	**166**	**94,2**	**168**	**96,8**	**174**	**94,0**	**172**	**91,5**
Support staff (research)	5	4,2	5	3,8	5	4,4	5	4,4	6	4,6	5	4,5
Total staff	**168**	**104,1**	**168**	**102,2**	**172**	**98,6**	**173**	**101,2**	**179**	**98,7**	**176**	**96,1**

Transport & Planning (TP)

	2017		2018		2019		2020		2021		2022	
Research unit	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	17	6,2	19	6,9	21	7,5	22	8,0	25	9,2	25	9,1
Assistant professor	8	2,9	8	2,8	8	2,9	9	3,2	10	3,5	8	3,3
Associate professor	4	1,4	5	1,9	7	2,4	7	2,6	9	3,4	10	3,5
Full professor	5	1,9	6	2,2	6	2,2	6	2,2	6	2,3	7	2,3
Researchers (2)	19	13,0	27	17,7	24	16,3	28	18,9	23	15,9	21	14,9
PhD candidates (3)	59	38,4	63	40,9	68	44,5	67	40,4	60	37,0	60	40,5
Total Research staff (1+2+3)	**95**	**57,6**	**108**	**65,6**	**113**	**68,3**	**116**	**67,3**	**108**	**62,1**	**106**	**64,5**
Support staff (research)	4	4,0	5	4,5	5	4,9	6	5,4	5	4,3	3	2,6
Total staff	**100**	**61,6**	**113**	**70,1**	**118**	**73,2**	**122**	**72,8**	**113**	**66,4**	**109**	**67,1**

Water Management (WM)

	2017		2018		2019		2020		2021		2022	
Research unit	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	26	9,5	26	9,8	28	10,8	29	10,9	28	11,0	29	11,2
Assistant professor	13	4,9	12	4,5	12	4,8	12	4,6	11	4,3	11	4,2
Associate professor	7	2,3	7	2,6	9	3,2	10	3,5	10	4,0	11	4,2
Full professor	7	2,2	7	2,7	7	2,8	7	2,8	7	2,8	7	2,9
Researchers (2)	18	13,7	19	12,8	24	15,6	27	17,4	21	13,1	16	10,3
PhD candidates (3)	143	88,8	148	88,4	136	81,5	136	84,3	139	80,4	137	75,8
Total Research staff (1+2+3)	**187**	**112,0**	**193**	**111,0**	**188**	**107,9**	**191**	**112,6**	**188**	**104,5**	**182**	**97,3**
Support staff (research)	4	2,9	5	3,8	6	4,5	8	6,0	9	6,5	9	6,9
Total staff	**190**	**114,9**	**198**	**114,7**	**194**	**112,4**	**199**	**118,6**	**197**	**111,0**	**191**	**104,2**

Materials, Mechanics, Management & Design (3MD)

	2017		2018		2019		2020		2021		2022	
Research unit	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	-	-	16	6,0	17	6,0	18	6,1	20	7,1	24	8,7
Assistant professor	-	-	9	3,3	9	3,0	9	3,0	11	4,1	13	4,9
Associate professor	-	-	3	1,2	4	1,5	4	1,6	3	1,2	4	1,5
Full professor	-	-	4	1,5	4	1,5	5	1,5	5	1,8	7	2,4
Researchers (2)	-	-	22	14,3	19	14,0	19	13,5	16	10,8	15	10,6
PhD candidates (3)	-	-	87	60,3	87	58,3	84	56,3	78	52,2	80	56,1
Total Research staff (1+2+3)	**-**	**-**	**125**	**80,7**	**123**	**78,3**	**120**	**75,9**	**113**	**70,2**	**119**	**75,4**
Support staff (research)	-	-	4	4,0	4	4,0	4	4,0	4	4,0	4	4,0
Total staff	**-**	**-**	**129**	**84,7**	**127**	**82,3**	**124**	**79,9**	**117**	**74,2**	**123**	**79,4**

B.2 Funding[44]

Table 32 Funding

All Civil Engineering Departments

	2017		2018		2019		2020		2021		2022	
Funding:												
Direct funding (1)	20.306.702	50%	18.162.055	44%	19.311.005	43%	19.935.010	46%	20.851.316	46%	23.051.704	45%
Research grants (2)	6.760.654	16%	7.760.175	19%	8.015.484	18%	7.262.268	17%	7.280.604	16%	6.902.509	13%
Contract research (3)	12.708.551	31%	13.899.003	34%	15.796.139	36%	14.630.613	33%	13.972.868	31%	18.809.311	37%
Other (4)	1.218.967	3%	1.558.788	4%	1.299.258	3%	1.856.840	4%	2.900.051	6%	2.686.175	5%
Total funding	**40.994.875**	**100%**	**41.380.021**	**100%**	**44.421.886**	**100%**	**43.684.731**	**100%**	**45.004.838**	**100%**	**51.449.698**	**100%**
Expenditure:												
Personnel costs	-32.303.562	79%	-35.780.065	86%	-37.975.594	84%	-36.876.356	88%	-38.378.426	88%	-42.664.813	86%
Other costs	-8.382.875	21%	-5.758.974	14%	-7.319.364	16%	-5.149.834	12%	-5.053.197	12%	-6.724.752	14%
Total Expenditure	**-40.686.437**	**100%**	**-41.539.039**	**100%**	**-45.294.959**	**100%**	**-42.026.190**	**100%**	**-43.431.623**	**100%**	**-49.389.565**	**100%**

Structural Engineering (StrE)*

	2017		2018		2019	
Funding:						
Direct funding (1)	8.589.960	50%	106.654	-902%	0	
Research grants (2)	979.478	6%	0	0%	0	
Contract research (3)	7.042.506	41%	-118.482	1002%	0	
Other (4)	511.176	3%	0	0%	0	
Total funding	**17.123.120**	**100%**	**-11.828**	**100%**	**0**	
Expenditure:						
Personnel costs	-13.541.397	80%	1.563	29%	0	0%
Other costs	-3.289.579	20%	3.908	71%	305	100%
Total Expenditure	**-16.830.976**	**100%**	**5.472**	**100%**	**305**	**100%**

* Structural Engineering (StrE) has been split up into two separate departments, Engineering Structures (ES) and Materials, Mechanics, Management & Design (3MD).

Engineering Structures (ES)

	2017		2018		2019		2020		2021		2022	
Funding:												
Direct funding (1)	0		2.668.935	34%	2.927.784	39%	3.255.742	42%	3.683.671	41%	4.318.149	35%
Research grants (2)	0		338.798	4%	686.163	9%	734.444	9%	832.453	9%	1.573.773	13%
Contract research (3)	0		4.577.236	58%	3.506.683	47%	3.528.819	45%	3.669.398	41%	6.080.880	50%
Other (4)	0		361.819	5%	323.273	4%	308.130	4%	776.145	9%	310.528	3%
Total funding	**0**		**7.946.788**	**100%**	**7.443.903**	**100%**	**7.827.135**	**100%**	**8.961.667**	**100%**	**12.283.330**	**100%**
Expenditure:												
Personnel costs	3.685	67%	-6.818.383	82%	-6.358.708	83%	-6.468.690	84%	-7.034.293	88%	-9.273.037	82%
Other costs	1.833	33%	-1.482.079	18%	-1.278.795	17%	-1.232.793	16%	-937.460	12%	-2.028.006	18%
Total Expenditure	**5.518**	**100%**	**-8.300.462**	**100%**	**-7.637.502**	**100%**	**-7.701.483**	**100%**	**-7.971.753**	**100%**	**-11.301.043**	**100%**

Hydraulic Engineering (HE)

	2017		2018		2019		2020		2021		2022	
Funding:												
Direct funding (1)	4.793.300	56%	4.474.335	48%	4.668.659	42%	5.095.989	51%	5.204.329	50%	5.700.235	50%
Research grants (2)	2.467.020	29%	2.659.989	28%	2.532.232	23%	1.811.494	18%	1.734.404	17%	1.678.557	15%
Contract research (3)	1.069.403	13%	1.992.969	21%	3.839.365	34%	2.790.537	28%	2.955.844	28%	3.138.910	28%
Other (4)	204.233	2%	248.373	3%	142.274	1%	340.082	3%	511.034	5%	849.979	7%
Total funding	**8.533.956**	**100%**	**9.375.665**	**100%**	**11.182.531**	**100%**	**10.038.102**	**100%**	**10.405.610**	**100%**	**11.367.681**	**100%**
Expenditure:												
Personnel costs	-6.749.355	79%	-8.229.240	88%	-10.167.092	87%	-8.537.726	89%	-9.283.863	89%	-9.803.578	87%
Other costs	-1.756.223	21%	-1.129.823	12%	-1.458.297	13%	-1.045.185	11%	-1.116.121	11%	-1.451.617	13%
Total Expenditure	**-8.505.578**	**100%**	**-9.359.064**	**100%**	**-11.625.389**	**100%**	**-9.582.911**	**100%**	**-10.399.984**	**100%**	**-11.255.195**	**100%**

Note 1: Direct funding (basisfinanciering / lump-sum budget)
Note 2: Research grants obtained in national scientific competition (e.g. grants from NWO and KNAW)
Note 3: Research contracts for specific research projects obtained from external organisations, such as industry, government ministries, European organisations and charitable organisations
Note 4: Funds that do not fit into the other categories

[44] According to Strategy Evaluation Protocol compulsory table E3

Transport & Planning (TP)

	2017		2018		2019		2020		2021		2022	
Funding:												
Direct funding (1)	2.784.958	44%	2.559.023	37%	2.578.475	34%	2.892.943	39%	2.857.579	36%	3.024.435	39%
Research grants (2)	1.193.996	19%	1.414.080	21%	1.601.770	21%	1.319.353	18%	1.477.000	19%	1.256.011	16%
Contract research (3)	2.116.487	34%	2.458.626	36%	2.952.991	39%	2.626.969	36%	2.669.815	34%	2.780.905	36%
Other (4)	220.058	3%	449.809	7%	443.214	6%	487.118	7%	908.482	11%	597.730	8%
Total funding	**6.315.499**	**100%**	**6.881.539**	**100%**	**7.576.450**	**100%**	**7.326.384**	**100%**	**7.912.875**	**100%**	**7.659.081**	**100%**
Expenditure:												
Personnel costs	-5.421.061	86%	-6.341.369	92%	-6.961.789	90%	-7.064.455	93%	-7.039.109	93%	-7.382.517	94%
Other costs	-901.011	14%	-582.918	8%	-731.330	10%	-548.983	7%	-523.041	7%	-455.639	6%
Total Expenditure	**-6.322.072**	**100%**	**-6.924.286**	**100%**	**-7.693.119**	**100%**	**-7.613.438**	**100%**	**-7.562.150**	**100%**	**-7.838.155**	**100%**

Water Management (WM)

	2017		2018		2019		2020		2021		2022	
Funding:												
Direct funding (1)	4.138.485	46%	4.098.889	45%	4.509.115	46%	4.585.816	41%	4.897.738	49%	5.095.597	50%
Research grants (2)	2.120.160	23%	2.648.191	29%	2.180.951	22%	2.565.472	23%	2.338.416	23%	1.425.176	14%
Contract research (3)	2.480.155	27%	1.960.814	22%	2.794.934	29%	3.576.520	32%	2.421.385	24%	3.056.452	30%
Other (4)	283.500	3%	317.825	4%	218.884	2%	499.092	4%	368.730	4%	560.425	6%
Total funding	**9.022.300**	**100%**	**9.025.720**	**100%**	**9.703.885**	**100%**	**11.226.901**	**100%**	**10.026.269**	**100%**	**10.137.649**	**100%**
Expenditure:												
Personnel costs	-6.595.434	73%	-7.300.401	81%	-8.017.429	78%	-8.427.153	84%	-8.066.759	82%	-8.354.865	83%
Other costs	-2.437.895	27%	-1.719.594	19%	-2.239.157	22%	-1.552.575	16%	-1.807.679	18%	-1.667.716	17%
Total Expenditure	**-9.033.329**	**100%**	**-9.019.995**	**100%**	**-10.256.585**	**100%**	**-9.979.728**	**100%**	**-9.874.438**	**100%**	**-10.022.581**	**100%**

Materials, Mechanics, Management & Design (3MD)

	2017		2018		2019		2020		2021		2022	
Funding:												
Direct funding (1)			4.254.219	52%	4.626.973	54%	4.104.521	56%	4.208.000	55%	4.913.288	49%
Research grants (2)			699.117	9%	1.014.367	12%	831.504	11%	898.331	12%	968.991	10%
Contract research (3)			3.027.840	37%	2.702.166	32%	2.107.768	29%	2.256.426	29%	3.752.163	38%
Other (4)			180.961	2%	171.613	2%	222.417	3%	335.660	4%	367.514	4%
Total funding			**8.162.137**	**100%**	**8.515.118**	**100%**	**7.266.210**	**100%**	**7.698.417**	**100%**	**10.001.957**	**100%**
Expenditure:												
Personnel costs			-7.092.235	89%	-6.470.577	80%	-6.378.331	89%	-6.954.401	91%	-7.850.816	87%
Other costs			-848.469	11%	-1.612.091	20%	-770.298	11%	-668.896	9%	-1.121.775	13%
Total Expenditure			**-7.940.703**	**100%**	**-8.082.668**	**100%**	**-7.148.630**	**100%**	**-7.623.297**	**100%**	**-8.972.591**	**100%**

Note 1: Direct funding (basisfinanciering / lump-sum budget)
Note 2: Research grants obtained in national scientific competition (e.g. grants from NWO and KNAW)
Note 3: Research contracts for specific research projects obtained from external organisations, such as industry, government ministries, European organisations and charitable organisations
Note 4: Funds that do not fit into the other categories

B.3 PhD candidates[45]

Table 33 PhD candidates

All Civil Engineering Departments

Enrolment				Success rates						
Starting year	Male	Female	Total (M+F)	Graduated in year 4 or earlier	Graduated in year 5 or earlier	Graduated in year 6 or earlier	Graduated in year 7 or earlier	Graduated	Not yet finished	Discon-tinued
2014	39	19	58	1 / 2%	14 / 24%	31 / 53%	36 / 62%	41 / 71%	6 / 10%	11 / 19%
2015	34	20	54	2 / 4%	12 / 22%	28 / 52%	37 / 69%	39 / 72%	11 / 20%	4 / 7%
2016	60	26	86	5 / 6%	23 / 27%	47 / 55%	56 / 65%	56 / 65%	14 / 16%	16 / 19%
2017	40	28	68	1 / 1%	18 / 26%	25 / 37%	25 / 37%	25 / 37%	36 / 53%	7 / 10%
2018	41	26	67	0 / 0%	9 / 13%	9 / 13%	9 / 13%	9 / 13%	52 / 78%	6 / 9%
Total	**214**	**119**	**333**	**9 / 3%**	**76 / 23%**	**140 / 42%**	**163 / 49%**	**170 / 51%**	**119 / 36%**	**44 / 13%**

Structural Engineering (StrE)*

Enrolment				Success rates						
Starting year	Male	Female	Total (M+F)	Graduated in year 4 or earlier	Graduated in year 5 or earlier	Graduated in year 6 or earlier	Graduated in year 7 or earlier	Graduated	Not yet finished	Discon-tinued
2014	1	1	2	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	2 / 100%
2015	0	0	0	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%
2016	0	1	1	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	1 / 100%
2017	0	0	0	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%
2018	0	0	0	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%	0 / 0%
Total	**1**	**2**	**3**	**0 / 0%**	**0 / 0%**	**0 / 0%**	**0 / 0%**	**0 / 0%**	**0 / 0%**	**3 / 100%**

* Structural Engineering (StrE) has been split up into two separate departments, Engineering Structures (ES) and Materials, Mechanics, Management & Design (3MD).

Engineering Structures (ES)

Enrolment				Success rates						
Starting year	Male	Female	Total (M+F)	Graduated in year 4 or earlier	Graduated in year 5 or earlier	Graduated in year 6 or earlier	Graduated in year 7 or earlier	Graduated	Not yet finished	Discon-tinued
2014	6	0	6	0 / 0%	1 / 17%	3 / 50%	3 / 50%	4 / 67%	1 / 17%	1 / 17%
2015	2	1	3	0 / 0%	0 / 0%	0 / 0%	1 / 33%	1 / 33%	2 / 67%	0 / 0%
2016	7	0	7	1 / 14%	2 / 29%	5 / 71%	6 / 86%	6 / 86%	1 / 14%	0 / 0%
2017	5	2	7	1 / 14%	3 / 43%	3 / 43%	3 / 43%	3 / 43%	2 / 29%	2 / 29%
2018	8	3	11	0 / 0%	1 / 9%	1 / 9%	1 / 9%	1 / 9%	10 / 91%	0 / 0%
Total	**28**	**6**	**34**	**2 / 6%**	**7 / 21%**	**12 / 35%**	**14 / 41%**	**15 / 44%**	**16 / 47%**	**3 / 9%**

Hydraulic Engineering (HE)

Enrolment				Success rates						
Starting year	Male	Female	Total (M+F)	Graduated in year 4 or earlier	Graduated in year 5 or earlier	Graduated in year 6 or earlier	Graduated in year 7 or earlier	Graduated	Not yet finished	Discon-tinued
2014	11	8	19	1 / 5%	4 / 21%	11 / 58%	12 / 63%	14 / 74%	3 / 16%	2 / 11%
2015	7	9	16	0 / 0%	2 / 13%	7 / 44%	10 / 63%	11 / 69%	3 / 19%	2 / 13%
2016	20	5	25	0 / 0%	3 / 12%	12 / 48%	16 / 64%	16 / 64%	7 / 28%	2 / 8%
2017	9	3	12	0 / 0%	4 / 33%	5 / 42%	5 / 42%	5 / 42%	7 / 58%	0 / 0%
2018	9	8	17	0 / 0%	2 / 12%	2 / 12%	2 / 12%	2 / 12%	12 / 71%	3 / 18%
Total	**56**	**33**	**89**	**1 / 1%**	**15 / 17%**	**37 / 42%**	**45 / 51%**	**48 / 54%**	**32 / 36%**	**9 / 10%**

[45] According to Strategy Evaluation Protocol compulsory table E4

Transport & Planning (TP)

Enrolment				Success rates						
Starting year	Male	Female	Total (M+F)	Graduated in year 4 or earlier	Graduated in year 5 or earlier	Graduated in year 6 or earlier	Graduated in year 7 or earlier	Graduated	Not yet finished	Discon-tinued
2014	1	4	5	0 / 0%	2 / 40%	3 / 60%	4 / 80%	4 / 80%	1 / 20%	0 / 0%
2015	5	3	8	0 / 0%	3 / 38%	7 / 88%	7 / 88%	7 / 88%	0 / 0%	1 / 13%
2016	9	8	17	4 / 24%	11 / 65%	13 / 76%	13 / 76%	13 / 76%	0 / 0%	4 / 24%
2017	5	4	9	0 / 0%	5 / 56%	5 / 56%	5 / 56%	5 / 56%	2 / 22%	2 / 22%
2018	6	4	10	0 / 0%	2 / 20%	2 / 20%	2 / 20%	2 / 20%	7 / 70%	1 / 10%
Total	**26**	**23**	**49**	**4 / 8%**	**23 / 47%**	**30 / 61%**	**31 / 63%**	**31 / 63%**	**10 / 20%**	**8 / 16%**

Water Management (WM)

Enrolment				Success rates						
Starting year	Male	Female	Total (M+F)	Graduated in year 4 or earlier	Graduated in year 5 or earlier	Graduated in year 6 or earlier	Graduated in year 7 or earlier	Graduated	Not yet finished	Discon-tinued
2014	13	5	18	0 / 0%	4 / 22%	7 / 39%	9 / 50%	11 / 61%	1 / 6%	6 / 33%
2015	9	5	14	1 / 7%	3 / 21%	5 / 36%	8 / 57%	9 / 64%	4 / 29%	1 / 7%
2016	19	10	29	0 / 0%	5 / 17%	12 / 41%	15 / 52%	15 / 52%	6 / 21%	8 / 28%
2017	13	13	26	0 / 0%	3 / 12%	8 / 31%	8 / 31%	8 / 31%	18 / 69%	0 / 0%
2018	10	10	20	0 / 0%	2 / 10%	2 / 10%	2 / 10%	2 / 10%	16 / 80%	2 / 10%
Total	**64**	**43**	**107**	**1 / 1%**	**17 / 16%**	**34 / 32%**	**42 / 39%**	**45 / 42%**	**45 / 42%**	**17 / 16%**

Materials, Mechanics, Management & Design (3MD)

Enrolment				Success rates						
Starting year	Male	Female	Total (M+F)	Graduated in year 4 or earlier	Graduated in year 5 or earlier	Graduated in year 6 or earlier	Graduated in year 7 or earlier	Graduated	Not yet finished	Discon-tinued
2014	7	1	8	0 / 0%	3 / 38%	7 / 88%	8 / 100%	8 / 100%	0 / 0%	0 / 0%
2015	11	2	13	1 / 8%	4 / 31%	9 / 69%	11 / 85%	11 / 85%	2 / 15%	0 / 0%
2016	5	2	7	0 / 0%	2 / 29%	5 / 71%	6 / 86%	6 / 86%	0 / 0%	1 / 14%
2017	8	6	14	0 / 0%	3 / 21%	4 / 29%	4 / 29%	4 / 29%	7 / 50%	3 / 21%
2018	8	1	9	0 / 0%	2 / 22%	2 / 22%	2 / 22%	2 / 22%	7 / 78%	0 / 0%
Total	**39**	**12**	**51**	**1 / 2%**	**14 / 27%**	**27 / 53%**	**31 / 61%**	**31 / 61%**	**16 / 31%**	**4 / 8%**

Appendix C
Additional Indicators

C.1 Academic Culture

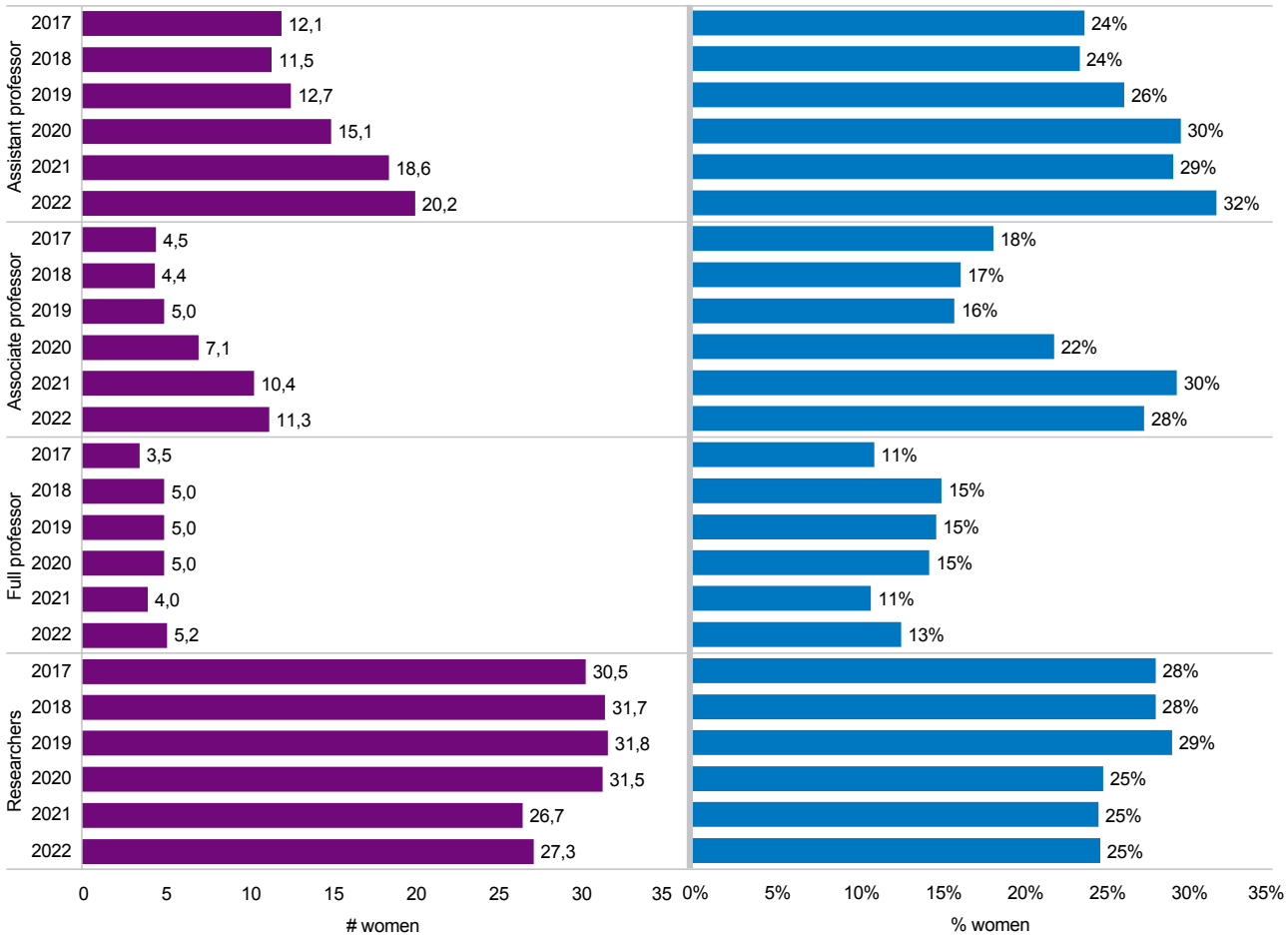
Table 34 Inclusion of early-career staff in decision making across departments

	WM	HE	T&P	ES	3MD
Is there a formal structure to include post-docs and Assistant Professors (early-career staff) in decision making?	**Yes**	**No**	**No,** but there is an ongoing effort to form a post-doc council.	**Yes,** but the so-called Young MT does not include post-docs.	**No**
If yes, are they represented in department MT Meetings?	**No**	**NA**	**Yes/partly.** The MT has 3 positions reserved for Associate/Assistant Profs.	**Yes.** The chair of the Young MT (who is elected every 6 months) attends MT meetings.	**NA**
If not, how do you involve early-career staff in the decision-making process?	Via department meetings.	This is left to the Section Heads (4 of whom are Associate Prof.).			
Are PhD candidates (and their council) represented and involved in the decision-making process?	**Yes.** PhD representatives are invited to the meetings of the department and of the Edu-team (monthly).	**Yes.** HE has a PhD Council, and meetings with Department Chair are held every two months. The board of the PhD Council is always welcome to attend the HE MT meetings.	**Yes.** A PhD council representative is a member of the MT (rotating role).	**Yes.** Post-docs and representatives of the department PhD Council can participate in the Young MT.	**No**
Other comments	Early-career staff (PhD, post-docs and Assistant Profs) are involved in lab organization, stimulated to participate in departmental/ Faculty committees, and think about desired changes for their involvement in the department organization.	Early-career staff are encouraged to attend the bi-monthly staff meetings and are actively involved in the agenda forming for those meetings. New early-career staff members are introduced in these meetings (“Meet the Academic Career tracker” agenda point).	The lab structure of T&P means that ALL Academic Career trackers and early-career staff are members of the Overlab and can take part in task forces established jointly by the MT and the Overlab.		Agenda and minutes and decisions of MT meetings are available to all staff and representatives of the PhD Council. Staff and PhD candidates can always ask for a topic to be discussed at an MT meeting and give their solicited and unsolicited advice. Task force groups are established with voluntary involvement of Academic Career trackers.

C.2 Human Resources Policy

Figure 44 Number (headcount) and share (percentage) of women in each staff category (A) and for PhD candidates (B). The headcount is adjusted for the availability of the staff member. That is, if a staff member starts in July, he/she will contribute 0,5 to the headcount.

A. The number (headcount) and share (percentage) of women in each staff category.



B. The number (headcount) and share (percentage) of women among PhD candidates.

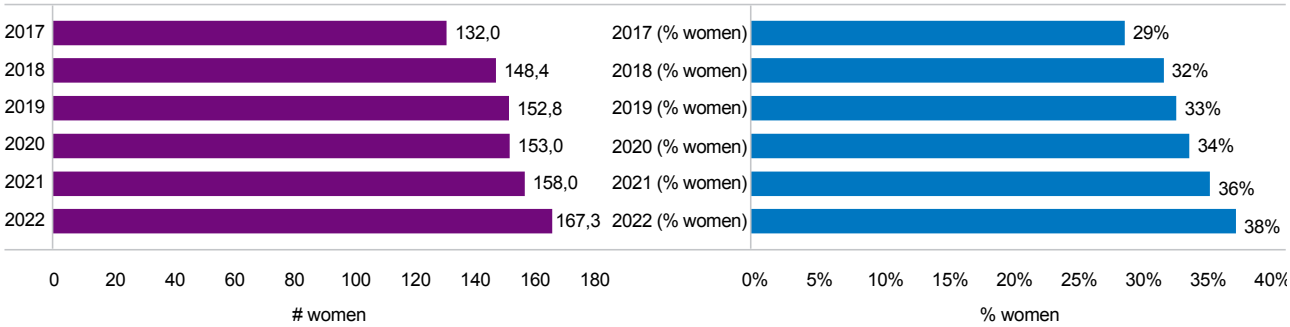
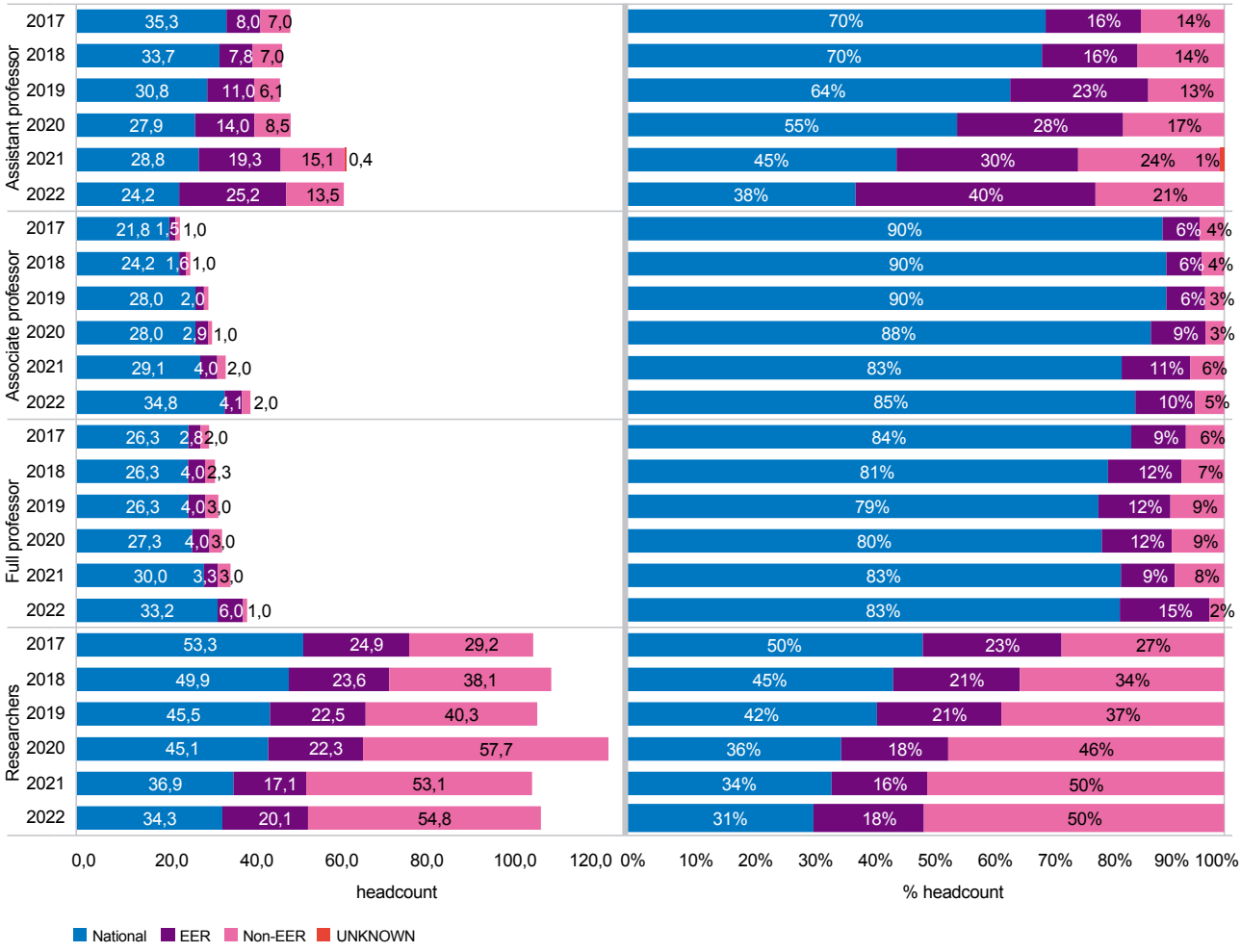
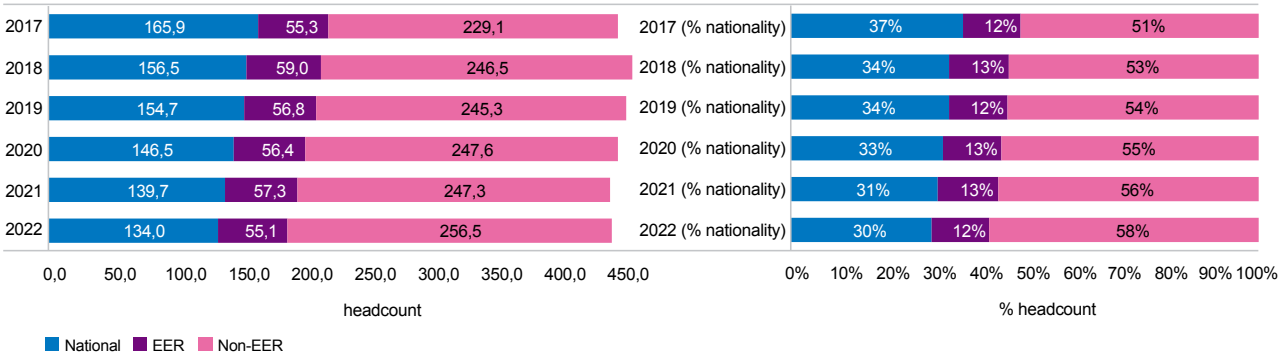


Figure 45 Nationality of staff members (A) and PhD candidates (B). The headcount is adjusted for the availability of the staff member. That is, if a staff member starts in July, he/she will contribute 0,5 to the headcount.

A. The number (headcount) and share (percentage) of the nationality of staff members in each staff category.



B. The number (headcount) and share (percentage) of the nationality of PhDs.



C.3 Additional tables and figures several departments

Transport & Planning

Table 35 Topics for each of the main themes in relation to the research done in each of the T&P labs. The scores of each lab are proxies for relative research time spent per topic.

		Thematic labs						Mode-agnostic labs					
Theme	Topics	AMLab	SPTLab	DRTLab	hEATlab	TDMac	F&L	TTS	UMO Lab	MXR Lab	SUM Lab	DittLab	AIM Lab
Urbanisation and Sustainable Transport	Safe & sustainable active mode transport (incl. micromobility)	20						5					5
	Vulnerable road users and driving automation							20		10			
	Multi-modal urban transport	10	6		10						15		5
	MaaS and Mobility-on-Demand		9								5		5
	Urban and regional public transport		12	5									3
	Electric and automated mobility		3		15	10					2	10	
	Emerging transport technologies and services	10	9	10	20		10			5	10	2	
	Integration of person and freight transport		2		2		10				5	5	
	City logistics and distribution						20				10		
	Coordinated and connected traffic management			10		25						3	5
	Demand management schemes		4										
	Densification and accessibility and 15 min cities										5		
	Car-low cities		4		10			5	10				
Climate-friendly Transport and Resilience	Electrification of transport				15		10						2
	Hydrogen-based transport			5									
	Future energy systems and role of transport			5	5		10						
	Sustainable multi-modal traffic management	5				10							5
	Energy-efficient driving for railway systems			15									
	Shared mobility: from ownership to use	10	9										
	Resilience in traffic and transport		5	10							10	5	5
	Crowd management, incl. evacuations	10							10	10			5
	Climate change adaptation in transport										5	2	
	Life-cycle analysis of transport systems		3										
	Decarbonising freight transport						20						
	Sustainable transport infrastructure	5										3	
Health, Equity, and Digitisation in Transport	Interactions between land use and transport innovation				3								
	Behaviour adaptation in response to transport innovation		3					10		5		5	
	Traffic and transport safety			5				25		5		10	
	Equity and inclusiveness in transport		9					5		5			
	Health and active mode mobility	10											
	Liveability and transport		2			10			10				
Computational Modelling and Analysis for Transport Engineering	Sensing, monitoring, and data collection	10		5				5	40	35			
	Data analytics and statistics		4			5		5	10	15		10	10
	Numerical modelling					5							
	Agent-based modelling	5	4			5	10			5		5	
	Mathematical modelling and analysis		4	5		5		5			15	10	10
	Optimisation		2	15	20	10	10						10
	Network science		4									5	5
	AI and ML, Integrated AI and combinatorial optimisation	5	2	5		10		5	20	5	18	10	25
	Risk analysis			5				10					
	Uncertainty quantification											15	
	Probabilistic design					5							

Water Management

Table 36 Internal & external collaborations and corresponding SDGs: 11 selected WM team-PI projects, funders, and their descriptions and connections to SDGs. These projects, some of which are ongoing, were selected for their alignment with our strategic vision for the next six years and with our research themes and involve multiple PIs (team-PI). Funders: European Commission (EC), Dutch Research Council (NWO), Indian Department of Science and Technology (DST), Indian Department of Biotechnology (DBT), Private Donors (PD), 4TU and TU Delft funding (TU Delft).

Project name (funder)	Team-PI Project Description	Key SDG
ToDrinQ (EC)	The project develops new technologies for real-time detection and monitoring of water quality and tests innovative treatment systems in order to deal with compounds and organisms of emerging concern such as pesticides, pharmaceuticals, disinfection by-products, heavy metals, and micro-organisms. *Team-PI: Dr. Rietveld, Dr van der Hoek, Dr Lompe* **Theme: Water, Health, and Disaster Preparedness**	6
Plantenna (4TU)	Plantenna is a collaboration between different groups affiliated with the 4TU federation that seeks to develop vegetation-integrated, energy harvesting, autonomous, high-resolution sensors that measure in-plant and environmental parameters at low cost. Novel sensors will enable early detection of plant-stress and environmental strain. This will, in turn, enable the optimisation of water and nutrient application schemes for climate-smart agriculture, improve drought protection and support decision making for environmental protection and climate resilience. *Team-PI: Dr. ten Veldhuis, Dr. Uijlenhoet* **Theme: Water, Food, and Climate**	2, 6, 13
TWIGA & TEMBO (EC)	TEMBO, a follow-up of TWIGA, is currently building cost-effective innovative sensor networks that can be financed by co-developing large socio-economic value in the fields of geo-hazards, water management, and agricultural information. *Team-PI: Dr. van de Giesen, Dr. Hut, Dr. Rutten* **Theme: Water, Food, and Climate**	2, 6, 7, 13
AGRICOAST (NWO)	With 2 PhD/1 EngD candidates at WM, this project focuses on field research, surface water and groundwater modelling, and treatment technology development to enhance water availability and quality for agriculture in the alinizinging coastal areas of the Netherlands *Team-PI: Dr. van Breukelen; Dr. Bakker, Dr. Abraham, Dr. Hoes, Dr. Lompe* **Theme: Water, Food, and Climate**	2, 6, 13
SARASWATI 2.0 (EC/DST/DBT)	Works to identify best available and affordable technologies for decentralised wastewater treatment with scope of resource/energy recovery and reuse in urban and rural areas, with participation of ten pilot technologies in 7 Indian states demonstrating enhanced removal of organic pollution. WM leads work on the development and advancement of models to simulate the biochemical processes for technology development and control algorithms to optimise process performance. *Team-PI: Dr. Lindeboom; Dr. Abraham,* **Themes: Water and Energy in Urbanising Deltas & Water, Health, and Disaster Preparedness**	6, 7, 11
SSF Next Century (NWO)	This project focuses also on unravelling the microbial processes in slow sand filters that relate to biodegradable organic carbon removal and their interaction with physical-chemical processes. The combination of this multidisciplinary research will improve our understanding of the working principles of SSF as well as novel designs and operation of slow sand filters, which will get SSF ready for the next century. *Team-PI: Dr. van der Hoek, Dr. van Halem, Dr. Foppen* **Theme: Water, Health, and Disaster Preparedness**	6

Project name (funder)	Team-PI Project Description	Key SDG
LOTUSHR (NWO)	While India is facing its worst water crisis in a decade, its rapid urbanisation keeps on putting more stress on fresh water supply, while water resources are simultaneously being polluted by untreated wastewater discharge. LOTUSHR demonstrates a novel, holistic (waste-) water management approach for the recovery of water, energy, and nutrients from urban wastewater. *Team-PI: Dr. de Kreuk, Dr. Medema, Dr. Lindeboom, Dr. van Halem, Dr. van Lier* **Themes: Water and Energy in Urbanising Deltas & Water, Health, and Disaster Preparedness**	3, 6
PUSH-IT (EC)*	PUSH-IT showcases the full-scale applications of heat storage of three different technologies in geothermal reservoirs at six different sites with various societal, heat network, and geologic conditions relevant across Europe. PUSH-IT will implement, develop, and test the ability of Mine, Borehole and Aquifer Thermal Energy Storage technologies (MTES, BTES and ATES) to store and recover heat. *Team-PI: Dr. Bloemendal, Dr. Vardon (GS&E)* **Themes: Water and Energy in Urbanising Deltas** ***Cross-department project**	7
Aidro Lab (TUD)	Fast and accurate AI tools are needed to model the physical processes within water networks and during flooding events. Using Graph Neural Networks or GNNs, the project explores AI-based digital twins of (urban) water systems for design, operational, and disaster contexts. By bringing together fundamental and applied AI, AidroLab aims to enable resilient and sustainable urban water systems. *Team-PI: Dr. Taormina, Dr. Langeveld, Dr. Kapelan* **Themes: Water and Energy in Urbanising Deltas & Water, Health, and Disaster Preparedness**	6, 9
African Water Corridor (PD)	The African Water Corridor is a WM-led initiative for sustainable development and the spread of research, innovative technologies, policies, practices, knowledge, and businesses to ensure that water is accessible and affordable to all, and no longer a limiting factor for development. With multidisciplinary science, technology, and innovation at the core of our work, we believe in implementation, testing our ideas in the field and that limited resources should not necessarily mean low tech. The initiative is building and fostering strong interdisciplinary relationships with a wide variety of stakeholders in selected corridors in sub-Saharan Africa, and in each location aims to grasp, plug, and solve water issues along development corridors. *Team-PI: Dr. van Halem, Dr, Rietveld, Dr. Abraham, Dr. van de Giesen* **Themes: This project is a thematic cross-over**	2, 6, 17
EPIC Africa (EC)	The EPIC Africa project, funded by an AU-EU innovation agenda programme, will build on open-source and transparent water-energy-food nexus models and resource modelling tools for the integrated assessment of future infrastructure planning at a basin or national scale. The project's goal is to support the governance of sustainable development in sub-Saharan Africa, which has the lowest energy access and irrigated agriculture levels in the world. Focusing on the Tana (Kenya) and Volta (Ghana-Burkina Faso) river basins, the project will co-design water-energy planning models and related policy for the coming decades, together with stakeholders and local research networks. *Team-PI: Dr. Abraham, Dr. van de Giesen* **Themes: Water, Food and Climate,** and **Water & Energy**	2,6,7,13, 17

Table 37 Summary of non-academic WM collaborators from industry and civil society. Collaboration includes joint projects, funding of research, co-supervision of (MSc/PhD) students/candidates, co-authorship publications (source: survey of WM academic staff).

Summary of non-academic WM industry and civil society collaborators		
1. Acacia Water	59. EYDAP Greece	120. Pidpa (BE)
2. AgroApps	60. FieldFactors	121. Project Maji (Ghana)
3. AKVO	61. Flowsand BV	122. Pure
4. Almere municipality	62. Foundation STOERR	123. PWN
5. ALTIS Groupe	63. FUGRO	124. PWN Technologies
6. Amsterdam Institute for Advanced Metropolitan Solutions (AMS)	64. FutureWater	125. Rainbow Sensing
7. Antea	65. G-ReD	126. Rijkswaterstaat
8. Aqualia	66. Garbageman (Bangladesh)	127. RIONED
9. Aquaminerals	67. GEUS (DK)	128. Rotterdam municipality
10. aQysta	68. GMB	129. Royal Netherlands Meteorological Institute (KNMI)
11. Arcadis	69. Grundfos	130. RoyalHaskoningDHV
12. Arnhem municipality	70. GSMA (UK)	131. RVO
13. Artesia	71. HCP International	132. SA SEBA
14. Balai Besar Wilayah Sungai Brantas (Indonesia)	72. HD-Rain (FR)	133. Sanquin
15. BASF	73. Heineken BV	134. Shell Global Solutions
16. Bioelectric	74. Heliostrome	135. Stichting Wateropleidingen
17. Biolegio	75. Het Waterlaboratorium	136. STOWA
18. Biotamax	76. HHNK	137. Sweco
19. Biothane-Veolia	77. HKV Lijn in Water	138. T-Mobile NL
20. Blijdorp Zoo	78. Hogeschool In Holland	139. TAHMO
21. BlueTec	79. Hogeschool Rotterdam	140. TAUW
22. BNNVara	80. Holland Greentech	141. Tereos Spanje
23. bNovate	81. HH de Stichtse Rijnlanden	142. Terneuzen municipality
24. Bolin Centre for Climate Research	82. HH Delfland	143. The Hague municipality
25. Science Panel for the Amazon	83. HH Hollands Noorderkwartier	144. The Ocean Cleanup
26. Potsdam Institute for Climate Impact Research (PIK)	84. Hoogheemraadschap Rijnland	145. Thorwash
27. Boskalis	85. HOST	146. TKI Water Technology
28. Brabant Water	86. HydroLogic	147. TNO
29. Breda municipality	87. HydroRock	148. Tomorrow.io
30. Broere Beregening BV	88. HYDS (SP)	149. TZW (DE)
31. CABOT	89. IF Technology	150. Utrecht municipality
32. CEBEDEAU	90. INERIS	151. Van der Valk + De Groot
33. Chemitech	91. InOpSys NV	152. Van Leeuwen Trenchless Tech
34. Colubris	92. Institute of Atmospheric Sciences & Climate (CNR-ISAC)	153. VanderSat (Planet BV)
35. Cosun	93. Intera	154. Veolia
36. Cyclopure	94. Irriwatch	155. Vewin
37. Delft municipality	95. Jotem	156. Vitens
38. Deltares	96. KNAW-Nioo	157. Vitens Evides International (VEI)
39. Dialog Axiata PLC (Sri Lanka)	97. KOERS	158. VITO (BE)
40. Disdrometrics	98. KWR	159. Vlaamse Milieumaatschappij
41. DOPS	99. Lenntech BV	160. W&F
42. DOW Chemicals	100. Magneto	161. Water Europe
43. Drainblock	101. Maptech Logistics	162. Waterlaboratorium Noord
44. Dunea	102. MicroStep	163. Watermaatschappij Drenthe
45. DVGW (DE),	103. Mobile Water Management	164. Watermaatschappij Groningen
46. Easymeasure BV	104. MTN (Nigeria)	165. Watermaatschappij Limburg
47. Ecoton (Indonesia)	105. Nelen Schuurmans	166. Waternet
48. Elemental Watermakers	106. Netatmo (FR)	167. Waterschap Aa en Maas
49. Environmental Agency East Java	107. Netherlands eScience Center	168. Waterschap Brabantse Delta
50. EPRC (Bangladesh)	108. Nijhuis Water Technology BV	169. Waterschap de Dommel
51. Erftverband	109. NIOZ	170. Waterschap Rijn en Ijssel
52. Ernst&Young	110. Noria Sustainable Innovators	171. Waterschap Vallei en Veluwe
53. EurEau	111. NPSP BV	172. Waterschap Vechtstromen
54. European Centre for Medium-Range Weather Forecasts (ECMWF)	112. NTUA Greece	173. Waterstromen BV
55. Evides	113. Nutrients Holding BV	174. Wetterskip Fryslân
56. Evides Industriewater	114. Oasen	175. Witteveen+Bos
57. Evoqua	115. Olisens	176. World Waternet
58. EWB	116. Orvion	177. WSHD
	117. Oxymem	178. Xylem
	118. Paques BV	179. Yara Sluiskil BV
	119. Perum Jasa Tirta 1 (Indonesia)	180. Zeolyst
		181. Zwolle municipality

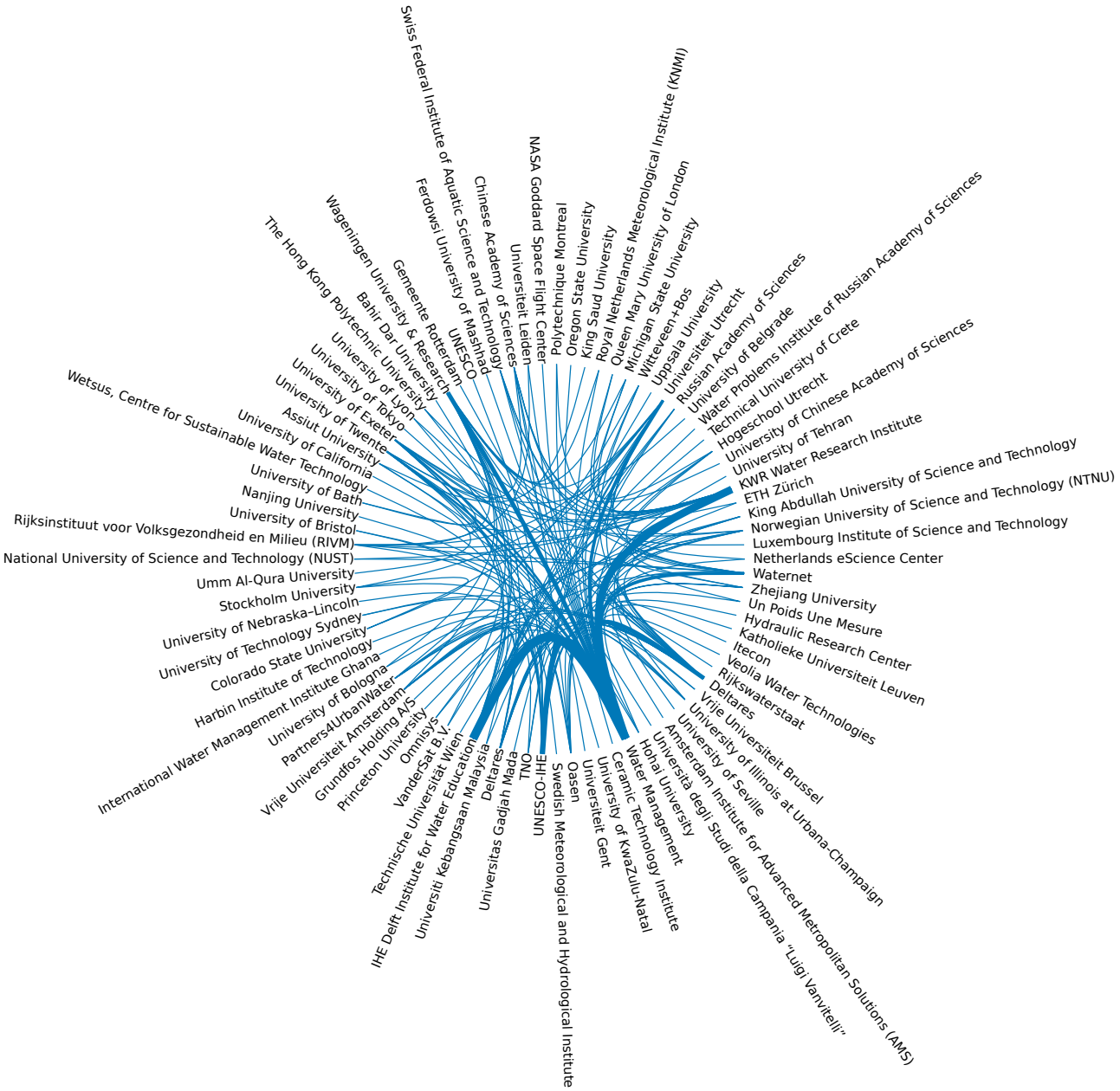


Figure 46 Diversity and strength (>4 joint publications) of WM's research collaborations (source: https://research.tudelft.nl/en/organisations/water-management/network-map/*).*

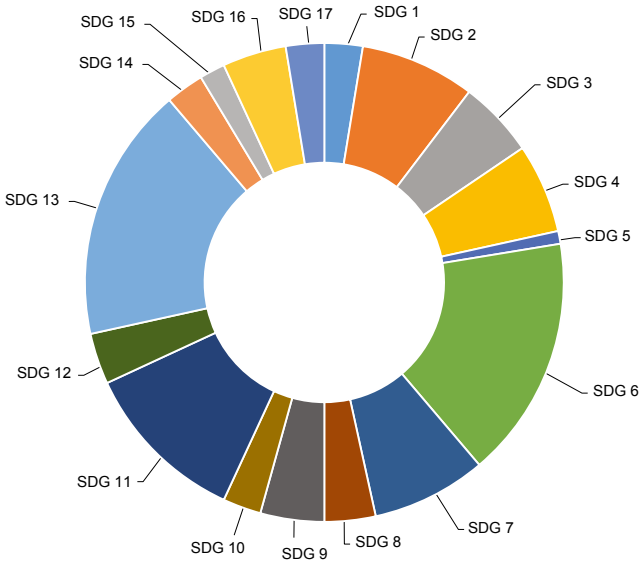


Figure 47 Distribution of SDGs[46] to which Principal Investigators at the WM department contribute with their research. All WM PIs contribute to one or more SDG (source: survey of WM academic staff).

[46] https://www.undp.org/sustainable-development-goals.

Appendix D

TRAIL Research School

What is TRAIL, why does it exist?

TRAIL is a research school in the area of Transport, Infrastructure and Logistics (TIL), in which six Dutch universities participate[47]. It is established for reasons of content (a multidisciplinary education program is provided), efficiency (join forces – efficient training of PhD candidates), quality (higher quality by selecting the excellent teachers (see Table 38), and community building (PhD candidates get to know many other PhD candidates and academics via TRAIL). On 01-09-2023, TRAIL had 138 PhD candidate members.

Previous assessment period included in this document

In 2016-2018 TRAIL was assessed as part of the Research Assessment TU Delft – CiTG for the period 2011-2016 (see section D.2). This document provides results for 2017-2022.

Criteria staff members

Academic staff can become TRAIL member if they fulfil criteria related to (a) being available for teaching, (b) supervising PhD candidates, and (c) publishing in peer reviewed, academic journals, and publishing reviewed book chapters (see Table 40).

Which activities?

TRAIL organises (a) PhD-level courses (on average about 15 courses per year), (b) a yearly PhD candidate conference, (c) seminars on selected TIL-topics, sometimes related to a PhD candidate thesis defence, and research meetings with the Ministry of Infrastructure and the Environment (see Table 41 for more details) and valorisation. In addition, TRAIL stimulates community building among PhD candidates and academics. Activity (a) is the most important from the perspective of training and educating PhD candidates. PhD courses and training meet the requirements for Doctoral Education at the participation Higher Education Institutes.

Evaluation results

The average score of all PhD courses for the years 2017-2022 was 8.2 average score per year respectively (scale ranging from 0 to 10), which is very high for Dutch standards. (see Table 43).

Valorisation

TRAIL organised several valorisation activities (see section D.6): (a) presenting and discussing the policy relevance of PhD theses, (b) discussing policy relevant topics (policy makers and TRAIL staff members), (c) organizing a yearly summer school for policy makers, and (d) organizing master classes for policy makers focusing on specific TIL-topics. In addition, employees of the Ministry participate in TRAIL-courses (teaching, following courses) and visit TRAIL-seminars and TRAIL-master classes.

Strategic choices

The management team of TRAIL is in the lead. It is supported by a supervisory board (representatives of the participating universities (deans), chaired by an independent chairperson), a program board (11 staff members being professors and a PhD candidate), and a PhD council (seven members of participating universities) (see section D.7).

[47] Delft University of Technology, Erasmus University, Technical University Eindhoven, Radboud University, University of Twente, and University of Groningen.

D.1 Full Professors[48] in the TRAIL program

Table 38 Full Professors in the TRAIL program

Delft University of Technology			
Prof.dr.ir.	B.	van	Arem
Prof.dr.ir.	C.G.		Chorus
Prof.dr.	R.M.P.		Goverde
Prof.dr.	M.P.		Hagenzieker
Prof.dr.ir.	R.		Happee
Prof.dr.ir.	S.P.		Hoogendoorn
Prof.dr.ir.	J.H.		Kwakkel
Prof.dr.ir.	J.W.C.	van	Lint
Prof.dr.ir.	L.A.		Tavasszy
Prof.dr.	G.P.	van	Wee
Eindhoven University of Technology			
Prof.dr.	S.		Rasouli
Erasmus University Rotterdam			
Prof.dr.ir.	R.		Dekker
Prof.dr.	H.		Geerlings
Prof.dr.	M.B.M.	de	Koster
Prof.dr.	R.A.		Zuidwijk
Radboud University Nijmegen			
Prof.dr.ir.	V.A.W.J.		Marchau
Prof.dr.	H.J.		Meurs
University of Groningen			
Prof.dr.	K.J.		Roodbergen
Prof.dr.	R.H.		Teunter
Prof.dr.	I.F.A.		Vis
Prof.dr.	D.	de	Waard
University of Twente			
Prof.dr.ir.	K.T.		Geurs

[48] This is a selection of the TRAIL staff members who are professor and actively involved in TRAIL Training and Education activities (2018-2023)

D.2 TRAIL assessment as part of the TU Delft CiTG Research Assessment

Committee:

Courses are specifically designed for TRAIL PhD candidates. The quality of the courses is regularly evaluated and overall PhD candidates are very positive about the courses. Suggestions for improvements, and lecturers who do not perform well are dealt with in a professional manner. The committee discussed the disciplinary field that is covered by the courses that are provided. For example, infrastructure is not explicitly part of a course, but is integrated in a number of courses. New courses are usually developed if sufficient PhD candidates are requesting a course on a certain topic. The committee understands that a minimum number of PhD candidates should be participating in a course, but at the same time recommends TRAIL to look into possibilities for courses on topics that are relevant for the discipline, but not meet the required number of participants. For example, courses can be provided once every two years. Another possibility might be to consider monetizing the courses, in order to gain funding to subsequently provide courses for smaller groups of PhD candidates.

Reaction of TRAIL:

TRAIL does indeed now organise some courses every 1.5 or 2 years in order to get sufficient participating PhD candidates.
(see also Table 43 to see the variation in the number of times course have been offered in 2017-2022). As for monetizing courses, TRAIL requests a fee from non-TRAIL members to participate. Faculties who are member of TRAIL do already pay a fixed fee per year which allows their PhD candidates to follow TRAIL-courses.

Committee:

The evaluation of individual courses is well organized. In addition, PhD candidates are required to fill out a form on the entire programme prior to their PhD defence. The committee considers that it would be interesting to analyse the value of TRAIL in respect to duration of the PhD and drop-out percentages of PhD candidates. It would certainly strengthen the position of TRAIL (and other national research schools) to be able to show added value to local graduate schools.

Reaction of TRAIL:

Although it would be really interesting, we think it is difficult to determine the value of TRAIL with respect to duration of the PhD project and drop-out percentages of PhD candidates. The reason is that many (and far more important) factors play a role in respect to duration of the PhD project and drop-out percentages, such as personal factors, quality of supervision, local graduate schools activities, and so forth. TRAIL plays a role in educating PhD candidates but we must acknowledge that our role in the whole PhD trajectory is rather indirect and relatively modest. What we do know is that the overall rate by PhDs for TRAIL 2017-2022 was 8.7. So we are appreciated but whether this appreciation has influenced PhD duration and drop-out rates we do not know.

Committee:

In the previous review report a number of minor remarks were provided, relating to bringing together the multiple TIL-disciplines within TRAIL and the positions of TRAIL PhD candidates in the overall training of PhD candidates.

Reaction of TRAIL:

In several courses as well as the annual TRAIL conference the multidisciplinary nature of TIL domain is lectured and highlighted.

Committee:

The committee verified that the relation between TRAIL and the local Graduate Schools has been improved and seems to function very well. Also the collaboration of different disciplines in the courses is adequate.

Reaction of TRAIL:

We will keep on doing this.

Committee:

The committee concludes that in the past period TRAIL has continued providing high quality courses to PhD candidates as well as provided community building. Issues that were mentioned in the previous report were responded to adequately. The committee is very impressed by TRAIL and considers that national research schools are a strong aspect of training young scientists in the Netherlands.

Reaction of TRAIL:

We agree upon this.

D.3 Criteria for becoming a TRAIL Staff member

Table 39 Overview of the different types of TRAIL memberships[49] and their criteria.

	TRAIL PhD candidate	TRAIL associated fellow	TRAIL fellow
Membership advantages	• Courses • Access to TRAIL symposia and conferences • Network to support your PhD research • Support for thesis publishing and advertisement PhD thesis • Guidance in planning PhD research	• Courses • Research network to support research proposal writing • Guidance in PhD supervision • Access to TRAIL symposia and conferences • Network	• Support cooperation between TRAIL researchers and external partners • Support in research funding/ acquisition • Courses • Platform for research dissemination • Access to TRAIL symposia and conferences • Network
Criteria	• A PhD candidate position at a TRAIL member faculty (employed at the university, externally funded but (temporarily) working at the university, or external PhD) • Supervisor should be PhD (associate) fellow • A basic PhD research plan, relevant for an area of interest of TRAIL • Follow the TRAIL educational program and take part in some TRAIL knowledge transfer activities (i.e. conferences) • PhD candidates who success-fully pass > 15 ECTS of courses receive a TRAIL-diploma	• A postdoc or higher position (0.2 or more) to a TRAIL member faculty • A plan for becoming a TRAIL fellow • Supervision of TRAIL PhD candidates, participation in the TRAIL courses and/or TRAIL knowledge transfer activities (i.e. The bi-annual TRAIL PhD conference)	• A postdoc or higher position (0.2 or more) to a TRAIL member faculty • One publication in an ISI journal as first author per year over the past 5 years. (co-authored papers count for 0.5) • (co)promotor or daily supervisor of TRAIL PhD candidates, participation in the TRAIL courses and TRAIL knowledge transfer activities

Candidates can be invited by the Scientific Director or candidates can proactively contact the TRAIL office for getting the application forms.

Within one month after receiving an application for membership, the Scientific Director of TRAIL will decide if to grant the application, and will inform the applicant of his decision. The Scientific Director will base the decision upon the criteria mentioned above and on the information provided by the applicant. If necessary, the Scientific Director may ask for additional information to the applicant. The Scientific Director may deviate from the formal criteria with a clear motivation.

An appointment as TRAIL member starts with the positive decision of the Scientific Director. The appointment ends when one of the requirements of membership – especially those related to the appointment of the member to the university – is no longer met. The criteria are (re-) assessed during an evaluation procedure. Membership also ends when the accreditation of the school is revoked.

The applicant may appeal against the decision of the Scientific Director, by submitting a request for a revision of the decision to the chairman of the TRAIL Board of Supervision. This board decides upon follow-up steps.

[49] All memberships are for free.

D.4 TRAIL Activities

Table 40 TRAIL courses[50]

Category	Courses
TRAIL skills	Introduction to TRAIL & the PhD candidate process [0.25 ECTS] [S][47]
I Basic TRAIL Courses	TRAIL Fundamental Domain Knowledge of TIL systems [1-4 ECTS] [D][51,52] TRAIL Theories and Methods [1-3 ECTS] [T,M]
II General TRAIL Courses	TRAIL Data analysis and statistics [1-3 ECTS] [S] Transport Innovations [0.5-1 ECTS] [D] TRAIL Writing a Literature Review in the TIL Domain [1-4 ECTS] [S] Writing and Publishing a TRAIL Research Article [0.5-1 ECTS] [S] Discrete Choice Analysis [2 ECTS] [T] Stated Choice Data Collection (1 ECTS] [T] Societal Relevance of your PhD Research [0.25-1 ECTS] [S] Machine Learning [1-4 ECTS] [M] T, I, or L basic disciplinary course[53] [1-3 ECTS] [D] (Writing a TRAIL research proposal (e.g. NWO) [1-3 ECTS][S])[54]
III TRAIL Specialisation Courses[55]	Traffic Flow Phenomena [1-3 ECTS] [I] Behavioural Aspects in Transport [0.5-1 ECTS] [I] Transport Logistics Modelling[49] [1-4 ECTS] [L] Facility Logistics Management[49] [1-4 ECTS] [L] Quantitative Modelling and Analysis of Supply Chains[49] [1-4 ECTS] [L] Advanced Inventory Theory[49] [1-4 ECTS] [L] Freight Transport Management[49] [1-4 ECTS] [L] Passenger Transport Systems[49] [1-4 ECTS] [L]

[50] For each course (except TRAIL skills I, DCA and STDC) we present two numbers for ECTS. The first number refers to participation only (no exam/assignment), the second to participation plus a successful exam/assignment. TUD GS has separate rules for awarding GS credits.
[51] Indicative classification of course type: D = domain knowledge, T = theory, M = methodology, S = skills. Note that Local GS and/or supervisors might deviate from this classification.
[52] Courses given by TRAIL and Research School Beta within the Graduate Program Operations Management and Logistics (GP-OML). See Appendix III for more information.
[53] TRAIL allows its PhD candidates to follow Master courses in the TIL domain at TRAIL- and non-TRAIL universities. The number of ECTS of PhD or Research Master courses count fully for the TRAIL program if additional to the TRAIL curriculum; for regular Master courses only 70% of the number of ECTS is included.
[54] Based on demand of TRAIL students/staff members.
[55] T: Transport, I: Infrastructure, L: Logistics

Table 41 Seminars on selected TIL-topics (related to a PhD candidate thesis defence)

TRAIL Masterclasses associated with PhD defences 2017-2022	PhD candidate	Attendants
Transport Models & Innovative Pricing Measures	Erik Sander Smits	24
Challenges in Railway Operations Planning	Nicola Besinovic	30
Advances in Coordinated Traffic Control	Goof van de Weg	29
Optimal Control Applications in Railway and Road Traffic	Pengling Wang	13
Advances in Road Traffic Modelling and Control	Yu Han	17
Analysing Freight Transport Networks	Hamid Saeedi	24
Disruptions, Emergencies, and the Resiliency of Transport Systems	Jeroen van de Gun	31
Managing Railway Disruptions and Large Delays	Nadjla Ghaemi	25
Incorporating Behavioural science into Transport Modelling for Facing Future Challenges of Vehicle Automation	Silvia Varotto	31
Microscopic Simulation for Road Traffic Operation and Safety Evaluation: current challenges and future opportunities	Aries van Beinum	24
Traffic Flow Estimation: applying simulation models and data estimation methods	Guus Tamminga	15
How to Provide a Better ITT Service in the Port?	Qu Hu	25
Modelling Travel Behaviour	Danique Ton	42
Optimization Models for Transportation Problems	Xiao Liang	20
Passenger and Disruption Management	Yongqui Zhu	9
Modelling Passenger Behaviour and Managing Public Transport Operations under Disturbances	Menno Yap	14
Applications of Data and network Science in Transportation	Panchamy Krishnan Krishnakumari	17
Internet access, automation and COVID-19: On the impacts of new and persistent determinants of travel behaviour (online)	Maria Alonso Gonzalez	30
Planning and Operations of Mobility On-Demand (online)	Jishnu Narayan	40
Driver Behavior and Traffic Operations with Automated Vehicles (online)	Lin Xiao	40
Road Network Design and Management for Automated Driving (online)	Bahman Madadi	20
Active Modes and the City (online)	Lara Zomer	24
Behaviour and Safety of Vulnerable Road Users in Current and Future Traffic (online)	Juan Pablo Nunez	23

D.5 Course evaluation results

Table 42 below gives an overview of the aggregate findings per T&E program element.
In general the following general remarks can be made:

- Most basic and specialization courses are given on a regular basis (i.e. once every 11.5 year).
- Courses that are given less frequent/cancelled involve specialization courses (e.g. Transport Innovations, Behavioral Aspects in Transport, Facility Logistics Management, Operations Research and Health Care , Public Transport, Transport Policy Analysis).
- Most courses have about 10 or more participants (informal threshold for courses of 1 ECTS or more).
- Most courses are graded highly by the students (between 7.5 and 8.5). Masterclasses on specific topics are very well attended.

Table 42 Overview of the aggregate findings per T&E program element.

TRAIL Courses [ECTS] and master classes within the period 2017-2022	Times given	# course days *(per course)*	Av. # students	Av. course assessm.	Course leader(s)
TRAIL skills I - Introduction to TRAIL & the PhD candidate process [0.25 ECTS]	5	0.5	13	8.6[56]	Marchau & Van Wee
Basic TRAIL courses					
TRAIL Fundamental Domain Knowledge of TIL systems [1-4 ECTS]	6	4	15	8.6	Annema & Van Wee
TRAIL Theories and Methods [1-3 ECTS]	4	3	15	7	Marchau
General TRAIL courses					
TRAIL Data analysis and statistics[5] [1-3 ECTS]	5	3	25	8.3	Kroesen & Molin
TRAIL Societal Relevance of your PhD Research [0.5-1 ECTS]	4	1	12	8.5	Annema & Van Wee
Transport Innovations [1-2 ECTS]	3	1	11	8.3	Geerlings, Annema, Wiegmans
TRAIL Writing a Literature Review in the TIL Domain [1-4 ECTS]	6	2	21	8.7	Van Wee
Writing and Publishing a TRAIL Research Article [0.5-1 ECTS]	4	1	14	8.3	Chorus & Marchau, Rezaei & Geurs
Discrete Choice Analysis [1-3 ECTS]	4	3	20	8.6	Chorus, & Van Cranenburgh
Stated Choice Data Collection [1 ECTS]	3	1.5	18	8.7	Rasouli & Caiati
Machine Learning [1-4 ECTS]	3	4	9	8	Almeida & Van Nieuwenhuyse
TRAIL Specialisation courses					
Traffic Flow Phenomena [1-3 ECTS]	1	3	12	8.4	Hoogendoorn & Van Lint
Behavioural Aspects in Transport [0.5-1 ECTS]	3	1	16	7.6	Brookhuis, De Waard & Veldstra
Transport Logistics Modelling [1-4 ECTS]	3	4	11	8.6	Tavasszy & Zuidwijk
Facility Logistics Management [1-4 ECTS]	3	4	9	8.6	De Koster & Adan
Quantitative Modelling and Analysis of Supply Chains [1-4 ECTS]	4	4	12	7.5	De Kok
Advanced Inventory Theory [1-4 ECTS]	1	4	6	8	Van Houtum & Dekker
Freight Transport Management [1-4 ECTS]	3	4	10	8.6	Vis
Public Transport [1-4 ECTS]	2	4	6	8.2	Cats & Schmidt

[56] Average assessment over the period 2017-2022.

Masterclasses on specific topics

Title	Day	Teachers	Attendants
The Role of Cities in Transitions towards Low-Carbon Mobility	0.5	Schwanen, Bertolini	16
The Future of Infrastructure Planning	0.5	Givoni, Meurs	33
Bike Share	0.5	Fishman, Maat	27
Expediting Future Technologies for Enhancing Transportation System Performance	0.5	Popper	18
A New Look at Accessibility, Transport and Well-being	0.5	Delbosc	27
How do travellers behave during disasters? A transport perspective on measuring, modelling and controlling evacuations	0.5	Various	12
Exploring Synchromodal Transportation Options with Simulation Gaming	0.5	Lukosch & Kourounioti	9

D.6 Valorisation

Presenting and discussing the policy relevance of PhD theses

2021

On 7 April, Prof. Serge Hoogendoorn (TU Delft / TRAIL). This year with the focus on the results of the ALLEGRO project (online)
On 9 September, Bert van Wee: Policy-relevant insights from dissertations from the TRAIL network (Online)

2020

On 20/05/2020, Bert van Wee: Online PhD thesis meeting (about 50 participants)

2019

On 21/03/2019 (Bert van Wee) TRAIL Lunch lecture on policy-relevant insights in the field of road safety
On 03/10/2019 (Prof. Lori Tavasszy, Prof. Vincent Marchau): TRAIL Lunch lecture: policy-relevant insights from doctoral research on freight transport

2018

On 4/6/2018 (Bert van Wee) - in-depth session 'Measuring is knowing, also for non-infrastructural measures'
On 8/11/2018 (Bert van Wee, Vincent Marchau) - in-depth session Inclusive transport: mobility for everyone?

2017 (full list of all thesis topics)

On 5/4/2017 by Bert van Wee:

- Residential satisfaction with highways and the influence of information and participation
- Complexity (breakthrough) of mobility behaviour
- Uncertainties in the 'hardness' of results from (activity-based) traffic models
- Coordination in the hinterland transport of ports

On 4/12/2017 by Serge Hoogendoorn:

- The influence of technology on accessibility, reliability, resilience, safety and sustainability
- The use of different data sources
- Utilization of (infrastructural) space
- Regional traffic and mobility management
- Design and ITS for walking and cycling
- Resilience of networks
- Impact of MaaS and responsive transit

Discussing policy relevant topics (policy makers and TRAIL staff members)

2020

On 09/09/2020, Prof. Prof. Bert van Wee, Dr. Mr. Niek Mouter, Prof. Serge Hoogendoorn, Prof. Erik Verhoef, Dr. Mark Lijesen: TRAIL lecture on COVID-19, transport measures and effects (about 120 participants)
On 29/09/2020, Prof. Bert van Wee a session on car sharing

2019

On 09/04/2019 (Prof. Bert van Wee, Prof. Bart van Arem, Dr. Rob Goverde en Dr. Oded Cats) - in-depth session on the capacity of the traffic and transport system
On 21/06/2019 (Prof. Bert van Wee, Prof. Erik Verhoef, Dr. Jan Anne Annema) - in-depth session Knowledge for climate

2018

On 4/6/2018 (Bert van Wee)- in-depth session 'Measuring is knowing, also for non-infrastructural measures'
On 8/11/2018 (Bert van Wee, Vincent Marchau) - in-depth session Inclusive transport: mobility for everyone?

2017

3/5/2017: Bicycle research and bicycle policy
30/11/2017: Mobility as a Service

Yearly summer schools for policy makers

- Summer school 2019: “Design with values | safe & circular”
- Summer school 2018: “Towards a climate-proof Netherlands | game & players”
- Summer school 2017: “Airport as a hub for sustainable innovation and transition”

Master classes for policy makers focusing on specific TIL-topics

2022

Date	Title	Given by
22 February	The Netherlands must quickly reflect on 'geo-economic' policy	Haroon Sheikh, Lori Tavasszy (TUD)
29 March	Climate change: shaping urban resilience	Mendel Giezen (UvA), Tina Comes (TUD)
31 May	Urban accessibility benefits from more vision and future-proofing	Sander Lenferink (RU), Karst Geurs (UT Twente)
27 September	Transitions: leaving the comfort zone and uncertainty	Prof dr. Paul Chan (TUD), Prof. dr. ir. Rob van der Heijden (RU)
25 October	The future of international passenger transport by rail	Dennis Huisman (EUR), Rob Goverde (TUD)

2021

Date	Title	Given by
16 March	Investing in hydrogen	Ad van Wijk (TUD), Coby van der Linde (CIEP)
26 April	The human among the algorithms	Inald Lagendijk (TUD), Jurgen Goossens (UvT)
10 June	Climate, drought and city	Niko Wanders (UU), Frans van de Ven (TUD / Deltares)
5 July	How do we keep it democratic in transitions?	Tamara Metze (WUR), Udo Pesch (TUD)
14 October	Cycling knowledge: with a U-turn to the future	Several speakers
11 November	The Water-Energy-Food Environment Nexus: opportunities for IenW?	Detlef van Vuuren (PBL en UU) en Joop de Kraker (UM en OU)

2020

Date	Title	Given by
23 January	Smart mobility hypes: what is really useful?	Bart van Arem (TUD), Hans Jeekel (TUE)
1 September	Beyond Corona: a sustainable city for everyone?	Ellen van Bueren (TUD), Marco te Brömmelstroet (UvA)
29 September	Aim for Happiness and Broad Prosperity	Akshaya de Groot (EUR), Jeroen Boelhouwer (SCP)
3 November	Smart and green shipping	Hans Hopman (TUD), Jasper Faber (CE Delft)
15 December	Biodiversity: what IenW can, must and wants to do with it	Louise Vet (ex-NIOO|WUR), Fransje Hooimeijer (TUD)

2019

Date	Title	Given by
30 January	The bicycle as a vehicle for transition	Researchers of the project Smart Cycling Futures
5 March	Greening of aviation – now & in the future	Jacco Hoekstra (TUD), Dick Simons (TUD)
21 May	Planet makes people, people make planet	Albert Faber (Ministerie EZK), Jaco Appelman (UU)
13 June	Transitions viewed economically	Herman Vollebergh (Tilburg University), René Kemp (MU)
31 October	Inclusive innovation: (how) does everyone participate?	Harro van Lente (MU), Ruth Oldenziel (TUE)
3 December	Satellite data for better policy	Pieternel Levelt, (TUD/KNMI), Ramon Hanssen (TUD/SkyGeo)

2018

Date	Title	Given by
22 February	Interconnectivity and Cybersecurity	Michel van Eet (TUD), Sandro Etalle (TUE)
19 March	Changed transportation systems	Albert Veenstra (TUE), Lóri Tavasszy (TUD)
23 April	Climate adaptation – a multiple challenge	Bas Jonkman (TUD), Stefan Kuks (UT)
22 May	Circular economy and other transitions	Aldert Hanemaaijer (PBL), Katrien Termeer (WUR)
5 June	More autonomous cars – more road safety?	Dick de Waard (RUG), Marieke Martens (UT)
18 September	'Broad prosperity' What & how in policy.	Bas van Bavel (UU), Jan Anne Annema (TUD)
12 November	The future of public transport	Niels van Oort (TUD), Henk Meurs (RU)
11 December	Public and private domains under pressure	Jeroen van den Hoven (TUD), Hiddo Huitzing (PBL)

2017

Date	Title	Given by
11 January	Seniors on the move – consequences of an aging population and silver lining for mobility	Frank van Dam (PBL), Wiebo Brouwer (RUG)
15 March	Accessibility of urban regions – towards a different vision and different approach?	Karst Geurs (UT), Pieter Hooimeijer (UU)
10 April	Equitable mobility	Bert van Wee (TUD), Karel Martens (RUN / Technion)
10 May	Climate policy under a new star	Klaas van Egmond (professor emeritus of UU)
5 September	Sustainable(more) aviation in a circular economy?	Paul Peeters (NHTV Breda), David Peck (TUD)
11 October	Dealing with uncertainty: dealing smartly with different futures	Vincent Marchau (RUN), Pieter Bloem, (staf Deltacommissaris)
12 December	Making consumer behavior more sustainable: what works and what doesn't?	Linda Steg (RUG), Jan Schoormans (TUD), Frank Dietz (PBL)

D.7 TRAIL Management

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List of figures

List of tables