Department of Hydraulic Engineering
Department of Transport & Planning
Department of Water Management
Department of Structural Engineering

Self-Assessment of Civil Engineering Research 2011-2016

TU Delft

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Stories of Science
The stories you will find in this document illustrate the diversity of the civil engineering research carried out at Delft University of Technology. Storytelling is the faculty's way of highlighting and sharing the research that happens behind its doors, in its labs and in the real world. All of our stories can be found on the official Civil Engineering & Geosciences story platform (www.citg.tudelft.nl/storiesofscience).

TU Delft

Contents

Self Assessment Civil Engineering 2011 -2016

1 Introduction to the civil engineering clusters of the Faculty of Civil Engineering and Geosciences (CEG) at TU Delft

1.1 Introduction to TU Delft

TU Delft was founded in 1842 as the Royal Academy for the education of civil engineers and has grown into a university with eight faculties, more than 23,0000 students and 3,000 scientific staff members. TU Delft's mission is "to make a significant contribution towards a sustainable society for the twenty-first century by conducting ground-breaking scientific and technological research which is acknowledged as world-class, by training scientists and engineers (education) with a genuine commitment to society and by helping to translate knowledge into technological innovations and activity with both economic and societal value (valorisation)". In the past few years, valorisation has developed into a full third core activity of our university, after education and research.

To explain the nature of research carried out at TU Delft, we use a classification in two dimensions as shown in Figure 1. 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. Both general research universities and universities of technology are primarily concerned with fundamental research. The difference between these two types of university 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 (GTIs; like 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 research. The common motivation, inspired by applications, forms the basis for our cooperation with industry. The difference in the nature of research is reflected in

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

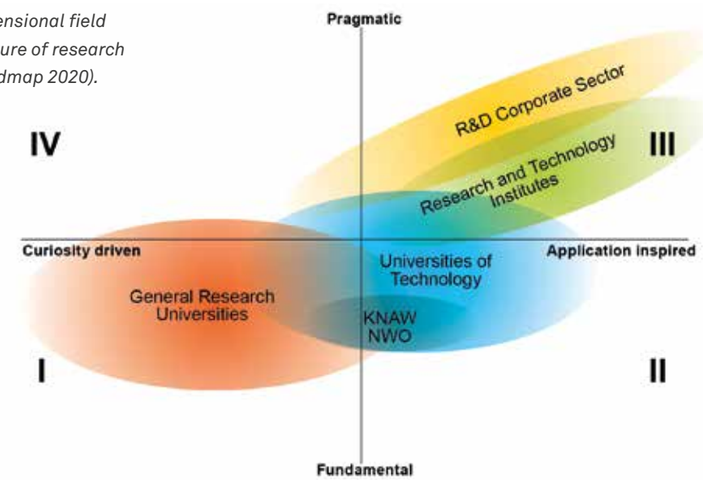
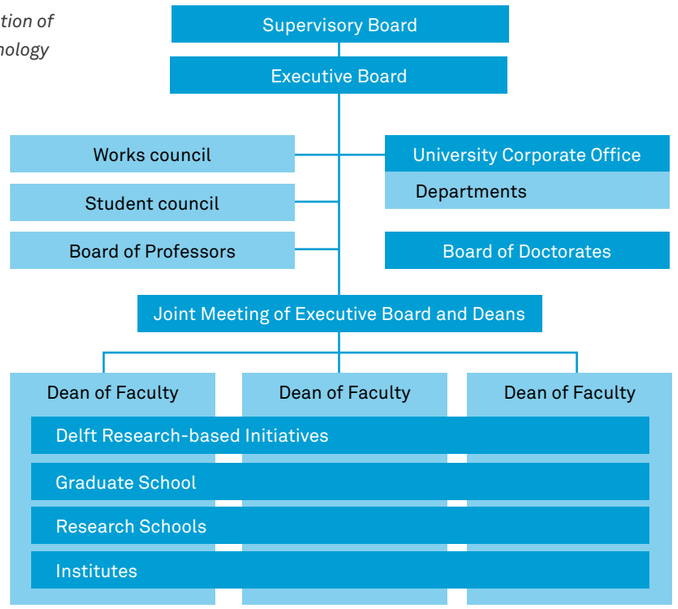


Figure 2: Main organisation of Delft University of Technology



the structure of many of our collaborative research contracts. Fundamental research questions are addressed in PhD and postdoc research projects, whereas the more pragmatic research questions and the implementation aspects are addressed by research staff from our partners at GTIs or 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 (DRIs) or in (inter)national programmes (Fig. 2).

1.2 Introduction to the Faculty

In short, the mission is to execute internationally leading research and eduction to contribute to a safe and sustainable living environment by educating engineers, conducting research and disseminate knowledge.

The Faculty of CEG strives to be at the global forefront in all key disciplines to realise technological contributions and breakthroughs for societal problems capitalising on its unique combination and interplay of excellent Science, Engineering and Design. Inspiration comes from many directions: the 17 sustainable development goals, the "Paris Agreements", the national 2050 CO_2-neutral target and the ever-accelerating high-tech developments, enabling new functionalities or efficiences. And, the Faculty's MSc and PhD students easily find jobs, all around the world.

Contributions by the Faculty in research are recognised world wide: in the recent Shanghai disciplinary ranking, TU Delft is number one in Water Resources and in Transport Science & Technology, for an important part due to results obtained at CEG. Since many years, Structural Engineering has been in the top-10 of the QS World University Ranking. In the 2017 rankings by the Centre for World University Rankings, TU Delft is in the top-10 in the following categories relevant to civil engineering:

- Transportation
- Transportation Science & Technology
- Ocean Engineering
- Construction & Building Technology
- Water Resources

The Faculty is led by its dean (Prof. Bert Geerken), overall responsible for research, education, valorisation and management. It consists of six programmes in the form of departments: two in geoscience (reviewed two years ago) and four in civil engineering (under evaluation now). Dean, heads of departments and the Faculty Director of Education form the management team (MT) responsible for the strategic decisions about research directions and major developments in educational and valorisation processes. Determination of the profiles for professor positions is an important subject on their agenda. The Faculty Secretary and the HR and Finance managers also participate in the MT meetings to guarantee a direct link to the execution of the decisions.

Facilities to support research at the Faculty range from modelling, simulation, field measurements and experiments in laboratories and in real-life settings. These facilities are mostly in-house labs and in many cases unique installations. Examples of large-field experiments are the mud engine (IJsselmeer), the sand engine (North Sea), and research in Estuaries (Zeeland, Wadden) or along rivers. In this review period, the shift towards virtual and real-life settings has accelerated. Examples of living labs are the Amsterdam-based Advanced Metropolitan Solutions centre and the field labs of the Valorisation Programme Delta.

1.3 Units to be assessed

The research units (programmes) that take part in this self-assessment are:

Hydraulic Engineering
(headed by Prof. Wim Uijttewaal)
Safety against flooding and the sustainable development of rivers and deltas is of utmost importance for our country and other deltas. Population growth and climate change put further pressure on this issue. Hydraulic Engineering develops knowledge about the physical and natural processes and link it to engineering models and design approaches in order to become to effective, sustainable and multi-functional solutions. The field of application covers the full range from the ocean to offshore and coastal areas and further inland to estuaries, rivers and lakes. Its recognition is worldwide.

Structural Engineering (headed by Prof. Jan Rots)
How can we move towards a zero-CO_2 and zero-energy future for safe and reliable building and infrastructure? Integrated, constructional design for civil infrastructure, constructional designs for buildings and new, sustainable or self-healing materials and their application in structures is the focus of Structural Engineering; intertwining science, engineering and design their approach. Societal themes such as 'durability' and 'sustainability' play an essential role. Object orientation on rail-infra, roads and bridges is important in Delft. Structural Engineering has recently been split and the resulting two new units are now led by Prof. Andrei Metrikine and Prof. Bert Sluys.

Transport & Planning
(headed by Prof. Bart van Arem)
How can we solve traffic congestion? Transport & Planning models transport systems with a focus on supply & demand, the opportunities of ICT and the influence of travel & driving behaviour. Intermodal transport systems and connecting infrastructure connects Transport & Planning to the Faculty of CEG. Collection, analysis and modelling define their robust and reliable transport solutions, respecting the scarce resources of land and environment.

Water Management
(headed by Prof. Luuk Rietveld)
Water crises are consistently the most mentioned global problems. Treatment and transport of drinking water, wastewater and industrial water (the urban water cycle) is a dominant theme in the Water Management research unit. Water quality and extraction of raw materials, water, and energy from the water cycle are focus areas as well. Not to forget drought, precipitation, floods and how water behaves in the atmosphere and beneath and on the Earth's surface. Many partners are found locally (IHE), in the region (companies) and internationally (also in developing areas).

1.4 Assessment 2005-2010

The Faculty of CEG was evaluated over the period 2005-2010 by an Assessment Committee (AC) within the same framework that we apply now, but according to a different SEP-protocol. At that time, renewal of themes and the enforced interplay with the stakeholders – both public and private – were the most prominent developments. The sound quality and promising potential of the civil engineering programmes were recognised by the AC. The AC made nine recommendations. These are briefly addressed in Appendix 1.

Figure 3: Funding of the Faculty of CEG over the years divided into the main funding pillars.

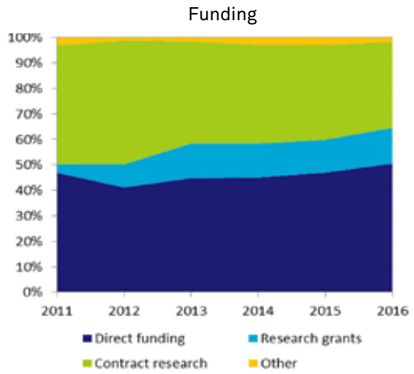
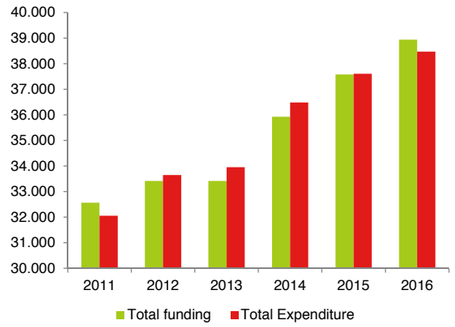


Figure 4: Funding vs expenditures of the Faculty of CEG.



2 Assessment of the clusters on the Faculty level

The assessment is to be based on the criteria research quality, relevance to society and viability. From the various performance indicators mentioned in the new SEP protocol 2015-2021, we identified the ones that are in line with our mission and the profile of our research. In general, all units report on these indicators in their self-assessment. Several indicators require quantitative data, which are presented in the form of tables; metadata are available in digital appendices. A table with performance indicators is provided for every programme to be assessed. The assessment also considers the aspects diversity, PhD programmes and research integrity. These aspects, together with funding (Ch 2.1) and HR-policy (Ch 2.2) are described here on the Faculty level (Ch 2.3 – 2.5).

2.1 Funding

In The Netherlands, the research funding scheme is divided into three pillars:

1. Direct funding: Internal funding allocated to the faculties/departments by the Executive Board of the university, originating from the Dutch Government.
2. National research grants: External funding, acquired in competition via various schemes from the Netherlands Organisation for Scientific Research (NWO).
3. Industrial and EU contracts: External contracts from industry are also mostly received in competition. EU contracts include regular EU projects, personal ERC Grants and Marie Curie Fellowships.

Figures 3 en 4 above, table 1 next page show the composition and dynamics (over the years) in funding and expenditures. The large decrease in direct funding in 2012 can be explained by a major budget cut due to a reorganisation on the university level. In all other years, the total amount of direct funding increased. This is partly due to the effects of a new allocation mechanism adopted within the university and partly because of an additional strategic allocation from the Board of TU Delft to cover the costs of the large laboratory facilities as part of the start-up package for newly attracted professors.
It is de-facto university policy that, post-docs' and PhD students' salaries are not paid by direct university funding so our acquisition policy shifted towards national funding and industrial & EU contracts. Governmental (direct) funds are achieved in competition and, although requiring matching funds in several cases, are valued highly because they contribute to the international academic reputation. This is especially true for personal research grants, e.g. the NWO Innovational Research Incentives Scheme (consisting of three types of grants, Veni - Vidi – Vici, in order of increasing seniority of the researcher). Industrial contracts, which mostly covers all integral costs, is important for a healthy balance in the budget. Within this domain, we aim to concentrate on projects that are scientifically attractive and offer potential for publication in refereed journals. Long-term consortium formation may also be of interest. Overall, we reduced our industry-based portfolio somewhat. A specific and growing funding scheme, in interplay with companies, is that of the Top Sectors, implemented by the Dutch Ministry of Economic Affairs in 2011.

Table 1: Overview of the funding and expenditures of the Faculty of CEG

Civil Engineering (4 units)	**2011**		**2012**		**2013**		**2014**		**2015**		**2016**	
Funding:												
Direct funding (1)	15.274	47%	13.750	41%	14.957	45%	16.190	45%	17.656	47%	19.664	51%
Research grants (2)	1.109	3%	3.026	9%	4.558	14%	4.765	13%	4.837	13%	5.456	14%
Contract research (3)	15.132	46%	16.247	49%	13.367	40%	13.940	39%	13.970	37%	13.158	34%
Other (4)	1.050	3%	387	1%	529	2%	1.030	3%	1.110	3%	657	2%
Total funding	32.565	100%	33.410	100%	33.411	100%	35.925	100%	37.573	100%	38.936	100%
Expenditure:												
Personnel costs	24.165	75%	24.663	73%	25.370	75%	27.982	77%	29.624	79%	30.626	80%
Other costs	7.885	25%	8.978	27%	8.583	25%	8.497	23%	7.979	21%	7.841	20%
Total Expenditure	32.050	100%	33.641	100%	33.953	100%	36.478	100%	37.603	100%	38.467	100%

Note 1: Direct funding (basic funding / lump-sum budget)
Note 2: Research grants obtained in national scientific competition (e.g. grants from NWO and the Royal Academy)
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

2.2 HR policy

TU Delft wants to be an attractive employer for talent, worldwide. We are always looking for top scientists with a passion for science, engineering and design, who want to work on ground-breaking solutions with societal impact. Also, we want to be an inspiring community for promising students who can commit their talents for technically outstanding contributions to science, society and economy.

In many areas we succeed in attracting promising scientists. Our positions in rankings and our (historic) reputation are helpful for that. Our facilities are widely recognised. Our salaries and limited start-up budgets may prevent science leaders to move to Delft.

Recruitment
Recruitment follows a strategic procedure, consisting of the following main elements: (1) departmental plans, (2) diversity policy and (3) the policy not to automatically replace retiring professors. Departments develop strategic personnel plans reflecting their ambition and the scientific development of the staff. In the departmental plans, all scientific staff are seen as principal investigators with the freedom to pursue their own research interests as they see fit, albeit within the boundaries of the section. Note that this policy deviates somewhat from the concept of principal investigator as used in the USA. At the Faculty level, a balance is found in the chairs, content-wise but also reflecting the organisational demand for capacity within the educational programme. An important phase in recruitment is the discussion on the domain and level (full professor, associate-, assistant professor) in the departments Management Team. The profile of the open position is described in terms of the departmental plan of the programme where the position will be embedded. Our main selection criteria are talent and quality. Recruitment of PhD's and postdocs depends on the acquisition of projects and the human resource capacity of the Faculty to supervise these researchers.

Personal development (including the tenure-track policy and the Result & Development cycle)
Next to attracting talent from outside the Faculty, the Faculty also emphasises the development of its current members: more than 30% of our assistant professors of 2010 became associate professor and approximately 20% of the associate professors became full professor. Promotions are made according to the standards set by the University and guarded by the Faculty's Career Committee (FCC). A special form of promotions is called the Antoni van Leeuwenhoek-chair. This is a personal chair granted by the University to an excellent associate professor within the TU Delft, acknowledging his/her quality and expressing confidence in the development potential of the candidate.
Recently, the universities in The Netherlands agreed to grant a selection of our associate professors the right of "ius promovendi" to better respect their actual role and to offer them a more prestigious position.

In order to keep track of the development of its employees, TU Delft uses a Result & Development (R&D) cycle linking the development of the organisation to the performance of its employees. In the R&D cycle, the performance of all employees is evaluated and agreements are made on their future development. The TU Delft R&D cycle consists of the following five steps: preparation, preview (preliminary consultation of supervisors), the R&D meeting between supervisor and employee (often also with the boss-of-the-boss present), review (evaluation consultation of supervisors) and feedback and implementation of the results.

The Faculty has adopted a tenure-track system for starting assistant and associate professors. The Faculty supports the tenure tracker with guidance from the scientific staff and advice of the different support services (e.g., a personal development programme from Human Resources, funding possibilities from the Valorisation Centre). The tenure tracker receives a midterm feedback from the FCC on whether (s)he is on track to reach a permanent position. Valorisation options related to their research are discussed with them as well.

The decision on transition from tenure-track to tenured, and the promotion from assistant to associate professor is taken by the Dean of the Faculty based on recommendations from the FCC. The members of the FCC include professors from all CEG departments as well as one from another TU Delft faculty. This enables to properly assess the academic level of the candidates and place it in a broader context. The FCC pays attention to the employees' progress in Science, Engineering and Design as well as to skills and accomplishments in education, management, and leadership.

As seen from Table 2, the Faculty has grown considerably in the past period. The growth in the number of (temporary) researchers (roughly doubled) and PhD candidates (+20%) exceeded that of our scientific staff (+15%).

Table 2: Research staff at the Faculty of CEG

4 Civil Engineering departments aggregated	2011		2012		2013		2014		2015		2016	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	159	43,5	164	45,4	171	46,2	174	47,6	174	48,2	178	50,2
Researchers (2)	129	47,3	132	46,7	148	53,2	192	72,3	197	81,3	255	103,3
PhD candidates (3)	399	233,8	422	260,1	435	267,7	457	269,3	464	264,4	480	279,5
Total Research staff	687	324,5	718	352,2	754	367,1	823	389,1	835	394,0	913	433,0
Support staff	25	12,6	25	12,4	28	12,7	35	13,9	31	14,7	32	17,2
Total staff	712	337,1	743	364,6	782	379,8	858	403,1	866	408,6	945	450,2

(1) comparable with WOPI category HGL (full professor), UHD (associate professor), UD (assistant professor), tenured and non-tenured
(2) includes post-docs and temporary 'onderzoekers'
(3) includes all PhD categories

2.3 Diversity

For TU Delft, diversity is important and interpreted broadly (age, culture/nationality, gender, social background, sexual orientation, disability and also in disciplinary background). Diversity in nationality is increasing: the percentage of international scientific staff has increased from 16 to 22%. The same trend is visible for researchers and PhD candidates.
Our CEG diversity focus is on gender, in particular on improving the recruitment and selection and career development of women. A number of instruments and policies have been implemented for recruitment and selection, PhD award policy, career development, increasing awareness and skills with regard to diversity and the balance between work and private life. An example is the Delft Technology Fellowship, which offers tenure-track positions to top female scientists within the fields of research of TU Delft. As Faculty, we implemented also an additional "gender boost" programme offering a personal fund to a restricted number of female assistant professors to achieve the level of associate professor within two years. Candidates are reviewed and selected by the FCC. They are invited to write a proposal on what they need for an accelerated development. Especially in Watermanagement this worked well, with two professor appointments in 2017.
Our strategy for raising the number of female candidates is to search for suitable candidates without strict limitations in advance. The list with potential candidates with a strong scientific profile is shared with the nominations advisory committee and the potential suitable female candidates are actively informed about this vacancy.
The Aspasia programme in the Netherlands is intended to encourage the promotion of female scientists to higher university positions where women are strongly underrepresented at present. Two Aspasia fellowships were awarded to female CEG scientists in this period, bringing the total up till now to five. Funds connected to these fellowships were used to stimulate the career perspectives of other female scientists within the Faculty, too.

From 2011 – 2016, the female-to-male ratio of scientific staff (professors, associates and assistants) gradually increased from 9:91% to the present 15:85% (see Appendix 2). Although this development is good, there is still a way to go to reach the set goal of 22:78% in 2020. Where the external influx, number-wise, represents the biggest impact on gender, the promotion of assistant to associate professors and to full professors shows that female careers are taken seriously.

2.4 PhD programme

Since 2012, TU Delft and the Faculty of CEG alike have greatly stepped up the attention they devote to PhD candidates. Driven by the realisation of how important PhDs are for the scientific performance of the university and for science in general, TU Delft has established its Graduate School (GS) in 2012 with the overarching goal of creating a stimulating environment and facilitating the growth of PhD candidates. Related goals were (and are) increasing the ability of the university to attract the best talents worldwide and to shorten the duration of PhD trajectories, which is presently acknowledged to be a significant problem (mentioned also in previous evaluations).

The GS is structured in Faculty Graduate Schools (FGSs), coordinated by the central Graduate School Board. Director of the FGS is prof. Giovanni Bertotti. The GS/FGSs focus on the following three aspects: Good supervision implies full attention to all steps of the PhD trajectory, from the search of the appropriate candidate to successful completion. The selection process, arguably the most important step of the PhD trajectory, is strengthened by a series of

Figure 5: Schematic representation of the stakeholders and networks involved in the supervision of PhD candidates at the Faculty of CEG

Table 3: PhD candidates in the Faculty of CEG.

Starting year	Female	Male	Total	Grad.	Grad. <= 4 yr		Grad. <= 5 yr		Grad. <= 6 yr		Grad. <= 7 yr		Not yet finished		Discontinued	
2008	17	42	59	46	5	8%	29	49%	41	69%	45	76%	1	2%	12	20%
2009	25	49	74	52	6	8%	21	28%	48	65%	52	70%	12	16%	10	14%
2010	23	60	83	45	3	4%	24	29%	40	48%	45	54%	25	30%	13	16%
2011	27	54	81	38	8	10%	33	41%	38	47%	38	47%	34	42%	9	11%
2012	14	41	55	9	1	2%	9	16%	9	16%	9	16%	38	69%	8	15%
	106	246	352	190	23	7%	116	33%	176	50%	189	54%	110	31%	52	15%

Note: This table includes Standard PhD candidates (with employee status) and Contract PhD candidates (without employee status, receiving external funding) conducting research with the primary aim/obligation of graduating, based on a 0,8-1,0 FTE contract. Please note that the data in the dark cells is incomplete. There are still PhD candidates active from those starting years that are able to graduate within the timeframe of the given years. Reference date: 1 januari 2017

guidelines such as the one requiring the interviews to be performed by more than one staff member. Having formally started their PhD in Delft, PhD candidates are exposed to various initiatives and coupled to a mentor who will support them for the entire duration of their PhD. After 6 months, a meeting is encouraged during which the supervisor and the candidate make sure that their expectations in terms of technical and human skills are aligned and that the candidate is well prepared for a meeting where it will be decided whether or not to continue the PhD trajectory (the GO/NO-GO meeting). The GO/NO-GO meeting (originally after 12 months but now anticipated to take place after 9 months) is a key moment. Moving away from the more traditional model, the GO/NO-GO interview is led by a committee which does not include the promotor who, however, is present in the meeting and who receives the recommendation of the committee and takes the final decision. Following the GO/NO-GO meeting, Yearly Progress Meetings are held, designed to steer the process. Progress of the PhDs is explicitly addressed in the yearly evaluations of staff members.
The Doctoral Education programme is a response to the need of widening the educational horizons of the PhD candidate by requiring him/her to participate in a number of courses and activities falling in the three domains of (1) specific technical knowledge (discipline-related skills and knowledge), (2) research skills (scientific research skills in general) and last but not least (3) "soft" skills (personal development; transferable skills). This reflects TU Delft's explicit ambition of educating engineers who are not only technically competent but also able to operate in complex environments characterised by multidisciplinary and multicultural interactions.
A tailored Doctoral Education programme should be completed before the defense of the doctoral dissertation. The Faculty Graduate School is responsible for training related to discipline and research. Discipline-related courses are often organised by Research Schools. The courses provided by the Research Schools have become part of the tailored Doctoral Education plans of the candidates. The TU Delft GS offers transferable skills training courses and support to further improve doctoral candidates' professional development.
Doctoral Monitoring Application (DMA) is a software tool designed to monitor the progress of each PhD candidate and to inform PhD candidates and supervisors on upcoming deadlines for the GO/NO-GO and yearly progress meetings. The DMA has proven to be a good tool not only to follow the paths of individual candidates but also to provide management information to the Graduate School to steer and improve PhD performance.
The Graduate School, which was at its infancy four years ago, is now a fully functional organisation, increasingly acknowledged and valued by PhD candidates and staff members alike. The TU Delft Graduate School is one of the most advanced graduate school in the Netherlands and is looked at as an example to be followed.

As the Graduate School was established in 2012, we expect to see the first results of its effect on the PhD success rate at the earliest at the end of 2016. The first results already show an increase in GO/NO-GO meetings taking place; especially the increase in the last year is substantial (76% → 94% from 2012 to 2015). We do however realise that approximately 50% of the GO/NO-GO meeting took place just after 12 months.
The effect of the Graduate School on the yearly progress meetings is not fully visible yet; the first years after the start of the Graduate School, data needed to be uploaded in the DMA and procedures needed to be secured. At the moment, the DMA is running in full force with a sharp reminding tool in order to remind stakeholders to hold GO/NO-GO and yearly progress meetings in time.

Table 3 shows the enrolment and graduation numbers of PhD candidates at the Faculty. The exit numbers include 'standard' PhD candidates (with employee status) and contract PhD candidates (without employee status, receiving external funding), all conducting research with the primary aim/obligation of graduating, based on a 0,8-1,0 FTE contract. The nominal PhD duration in the Netherlands is four years. However, the defence often takes place in the 5th year, in part because of a delay between finalising the thesis and the actual defence date. Therefore, a thesis finished within 5 year is still considered to be successful. A total of 15% of the PhD candidates discontinued their PhD research. This is too high. With the establishment of the Graduate School we expect to decrease this number significantly. In addition to the above-mentioned PhD categories, the Faculty has a considerable number of part-time PhD candidates: internal and external candidates who spend less than 0,8 fte to work on their thesis. These are not included in the table.

2.5 Research Integrity

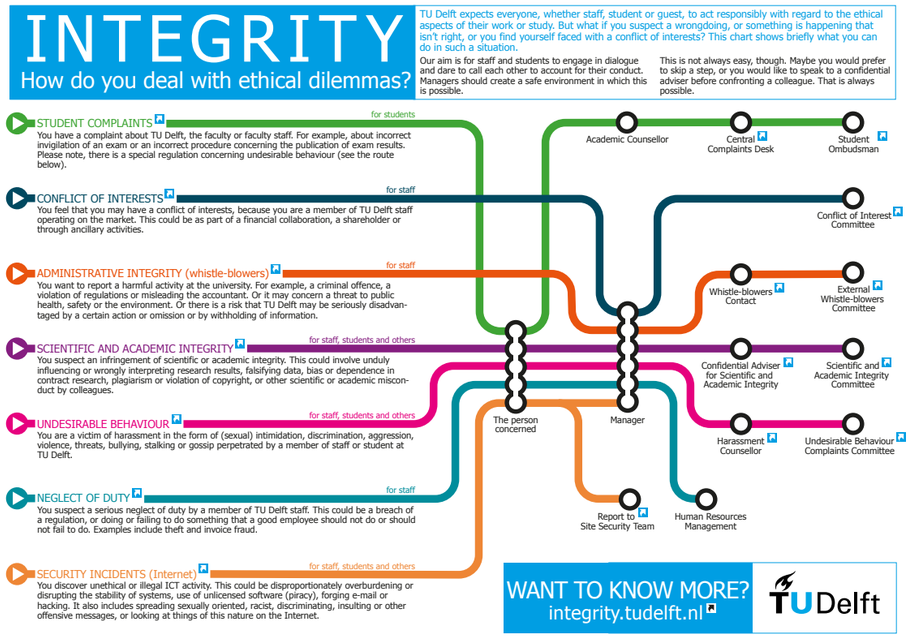
Measures to safeguard research integrity

- TU Delft has set guidelines down in a "Code of Ethics TU Delft". This Code of Ethics formulates the ideals, responsibilities and rights that should be taken as guidelines for everyone who is part of TU Delft: the academic staff, support staff, guests and students. All letters of appointment refer to this Code of Ethics.
- All new PhD candidates follow the PhD course on scientific integrity, which is a half-day introductory training course that is part of the obligatory PhD Start-up Programme. The course focuses on (moral) questions that are important to consider for researchers at the start of their academic career. It aims to help PhD candidates to gain insight into societal, moral and public aspects of their work, like societal responsibilities, intellectual property and co-authorship. PhD-candidates can also follow an engineering ethics course.
- The TU Delft Scientific and Academic Integrity Complaints Regulations include a complaints procedure for situations involving breaches of scientific or academic integrity that may occur within the organisation.
- All thesis manuscripts are automatically screened by TU Delft for plagiarism as of January 2015 using an online tool. A report of this screening is sent to the promotor to be checked and signed off before the promotion ceremony can be held.
- Employees who take on other paid and unpaid duties need to ensure that these are not at the expense of or at variance with their professional duties at TU Delft, and that they do not compromise their impartiality and independence. Secondary employment may not adversely affect the scientific or business interests of the university. Procedures for obtaining permission for various types of ancillary work are part of the publicised regulations and procedures of TU Delft (TU Delft Regulations on Secondary Employment). It is standard policy that all employees are transparent on their other jobs/appointments and that they publish these secondary employments on their so-called people pages on the TU Delft website. The TU Delft Conflict of Interest Committee issues recommendations to the Executive Board on cases submitted to it concerning possible conflicts of interests involving a member of staff who is also engaged in market-related activities in addition to his or her position at TU Delft.

Data storage and accessibility

Accessible and durable storage of data, for future consultation by TU staff and external parties, is considered a major aspect of research integrity within the TU Delft. Data that are essential to prove the integrity and ownership of our research outcomes should be retained in a durable and appropriately referenced form for at least 5 years from the last publication. The procedure has been developed in late 2014/early 2015 by a small working group at TU Delft and brought into a pilot stage in 2015. The procedure concerned various data types, i.e. measured, collected and/or numerical computed data, as well as source code. Its implementation was carried out in close cooperation with the TU Delft Library, which takes part in the 4TU Datacentre. Whenever

Figure 6: TU Delft Integrity Roadmap, designed to help anyone who suspects a wrongdoing, notices that something isn't quite right, or find him/herself faced with a conflict of interests.



possible, the data are uploaded in the Repository of the 4TU Datacentre. This specialised organisation ensures long-term (15 years) accessibility and data maintenance despite changing software and technologies over time, full data protection (against corruption) and restoration of data after loss or damage by accident, breach of security or natural disaster. A good example of storing and sharing research data during the research is the use of the OpenEarth datalab platform for the Sand Engine project in which TU Delft collaborates.

In 2015, the TU Delft has defined and implemented her Research Data Management policy. This policy focusses on the complete lifecycle of research data: from collecting, storing, archiving and re-using. Researchers are supported by research management support. The Faculty of Civil Engineering and Geosciences is one of the frontrunners within the university in the use of the 4TU.Centre for Research Data and on implementing a data stewardship policy and thus making its way of dealing with all sorts of research data more explicit.

3 Strategy

3.1 Current strategy

Context
The challenges we consider in drawing up our strategy line up with the 17 sustainable development goals of the United Nations and with the global risks as identified by the World Economic Forum. The reports by these organisations put current and foreseen scientific challenges in a new perspective and emphasise the need and urgency of new technologies to support the development, adaptation to and mitigation of the greatest risks we face.

Vision
The vision of the Faculty is to contribute to solutions to these challenges by performing application-driven research and providing research-driven education. Central themes as addressed by the European Union as the Grand Societal Challenges and those of the Dutch Top Sectors are Environment, Infrastructure, Mobility and Energy.

Strategy
Research at TU Delft can be characterised as seeking answers to application-driven questions in a fundamental way. The complexity of the research questions which are posed demand that many of them have to be tackled in a multidisiciplinary or interdisciplinary way. Engineering disciplines bend towards a fundamental approach in the research. We believe in a stimulating balance between science, engineering and design for developing renewed engineering technologies.

It is the ambition of the Faculty of CEG to reinforce its role in the regional, national and international dynamics, were we aim to be counted among the world-leading institutes. To reach this, we focus on visibility, growth of individuals (scientific quality) and creating connections between the themes (connectivity) within the faculty and our peers.

Structures & collaboration
The research groups of the Faculty of CEG are traditionally embedded in six programmes, of which four (denoted by an * in the list below) take part in the current self-assessment:

- Hydraulic Engineering*
- Structural Engineering*
- Transport & Planning*
- Water Management*
- Geoscience & Engineering
- Geoscience & Remote Sensing

This division into separate programmes should and does not hinder intra- and interprogramme cooperation. Still, the Faculty invested in promoting cooperation between programmes and Faculties (connectivity policy). This type of cooperation is hard to get funded via funding agencies, which focus mainly on cooperation between universities and countries instead of within universities and faculties. Through this policy, cooperation is stimulated for example between the Geoscience & Engineering and Hydraulic Engineering programmes with a tenure track on foundations of offshore structures, between the Structural Engineering and Water Management programmes with a tenure track on asset management of urban water infrastructure and between Structural Engineering and Transport & Planning on Road and Railway engineering. Figure 7 shows the collaboration between scientists of different CEG programmes as measured by their combined scientific output.

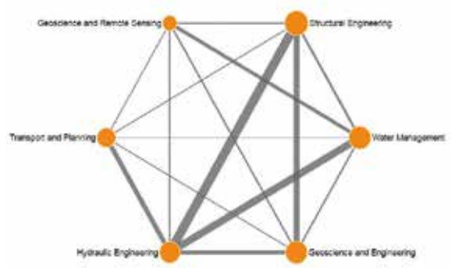
TU Delft also promotes interdisciplinary cooperation and has – apart from interuniversity coordination – locally established the Delft Research-based Initiatives (DRIs) and the Delft Institutes. DRIs are aimed to engage with government and industry, identify important opportunities and actively spotlight innovative science. The four CEG programmes participate in the Delft Deltas, Infrastructures & Mobility Initiative (DIMI), the Delft Energy Initiative and the Delft Global Initiative.

Delft Institutes cluster high-quality research capacity on specific research themes. Each institute aims to further raise the international profile to better position to join national and international consortia and networks, and also make TU Delft more attractive to top scientific talent. The CEG programmes are part of 6 Delft Institutes, as listed in the matrix on the next page.

Developments within society and research fields influence our research practice and organisational focus. In this reporting period, for example, research on urban water infrastructure, automated driving and earthquakes were newly embedded. In each case, we started with focussing research of existing faculty members and acquiring new PhD projects on the subject and – if succesfull - recruiting dedicated staff members and establishing a visible research line/chair.

Basis of research
The basis of our research capacity is provided by our staff members. PhD projects and postdocs give additional substance to the research. We expect our staff members to acquire projects and guide the PhD candidates and researchers. The European Union (H2020 programme), NWO, industry and arrange-

Figure 7: Collaboration between CEG programmes as measured by their joint scientific output.



Matrix of Delft Institutes and CEG programmes

Institutes	Hydraulic Engineering	Structural Engineering	Transport & Planning	Water Management
Climate	●			●
Transport		●	●	
Safety & Security	●	●		
Wind Energy	●	●		
Computational Science and Engineering		●		
Bioinstitute		●		●

ments with governmental organisations (bodies like RWS and ProRail) are our greatest contributors. Our focus is on peer-reviewed articles but conference contributions still play an important role in engineering and design.

Applying for personal excellence-grants, both European (ERC Starting-Consolidator-Advanced grants) and Dutch (NWO Veni–Vidi–Vici grants), is promoted by the Faculty. In the different phases of their career, scientists are informed, stimulated and supported. Granted funds reflect on the quality of the scientist and the Faculty but also provides more chance to shape individual research programmes by the open nature of the grant.

Cooperation in multipartner programmes
Research is more and more done in cooperation with other parties. This is not only the case with external funding from industry, but also in projects funded by NWO and the EU. Within the H2020 pillar Industrial Leadership and the Topsector-related NWO calls, the support of industry in the research project is an essential condition. In H2020, the participation of multiple partners from different countries and backgrounds is obligatory.
The number of research projects which are being conducted by a single Principal Investigator are decreasing. Nowadays, single-PI projects are limited to personal grants like ERC and NWO Vernieuwingsimpuls (Veni-Vidi-Vici). The four programmes have been and are successful in acquiring both cooperative and personal excellence projects.

The Faculty has been successfull in getting awarded several prestigious personal grants:

Grant	Scientist	Theme	M	F
ERC Advanced Grant	Prof.dr. Serge Hoogendoorn	Unravelling pedestrian and cyclist flow in cities	●	
ERC Advanced Grant	Prof.dr. Marcel Stive	Nearshore Monitoring and Modelling: Inter-scale Coastal Behaviour	●	
ERC Consolidator Grant	Dr. Angelo Simone	Structural Batteries	●	
NWO Vici grant	Prof.dr. Serge Hoogendoorn	Travel Behaviour and Traffic Operations in case of Exceptional Events	●	
NWO Vidi grant	Dr. Caroline Katsman	Eddies & sinking of ocean waters		●
NWO Vidi grant	Prof.dr. Susan Steele-Dunne	How thirsty are crops?		●
NWO Vidi grant	Prof.dr. Merle de Kreuk	The effects of suspended solids on granular sludge		●
NWO Veni grant	Dr. Matthieu de Schipper	Feeding starved coasts by natural morphological diffusivity	●	
NWO Veni grant	Dr. Victor Knoop	Integrated driving behavior theory and models: there is plenty of room in the lane	●	
NWO Veni grant	Dr. Frans van der Meer	Simulating rupture growth in composites	●	
NWO Veni grant	Dr. Miriam Coenders	Discovery of the invisible water drain evaporation		●
NWO Aspasia grant	Dr. Winnie Daamen	Crowd Management		●
NWO Aspasia grant	Prof.dr. Merle de Kreuk	Hydrolysis processes in sludge digestion		●
NWO Aspasia grant	Prof.dr. Susan Steele-Dunne	How thirsty are crops?		●

Valorisation
For successful innovation, constructive cooperation is as important as knowledge and creativity. In order to be able to transform technological innovations into applications that bring added value to society, we engage the help of external partners. By working with industry, government and civil society organisations or directly with individuals, we can offer our knowledge for the benefit of society.
Cooperating with third parties within projects is almost standard, partly because of our focus on innovative engineering technologies for those parties and partly because funding agencies demand involvement of such parties in proposals. Our projects generate intellectual property (IP) which is often transferred to our partners with royalties or other contributions in return. If IP is owned by the Faculty we follow the corporate strategy (sell, license or participate in a company with the IP as investment). We have several good examples within the Faculty of longterm cooperation with research (such as RIONED, ProRail and with the Port Authority of Rotterdam). We favour such mechanisms also because they provide us with stability over time.

3.2 SWOT of the Faculty

See next page.

3.3 Future strategy

Our main assets are and will remain staff and strong reputation. Proper recruitment, retention and development of staff members is of utmost importance. The further implementation of our HR policy will support this. New practices include more open recruitment, publishing vacancies for staff members irrespective of the seniority level and a less strict description of the research subject, which is also relevant for our gender policy. Further attractiveness is expected from the recently introduced tenure track-system, the allocating start-up grants, the increased possibilities of Antoni van Leeuwenhoek professorships and granting the Ius Promovendi to associate professors. In the upcoming period we will be focussing on the organisational development towards more autonomy and responsibility for our staff members, combining a team approach with the Principal Scientist model.

An open attitude and cooperation is part of our national culture. These days, an interdisciplinary approach is required to be able to answer the research questions in relation to societal needs, which become more and more complex. The process of creating broad coalitions is however time consuming and tends to create structures with bureaucratic burden. Therefore, it is important to improve support functions. Work pressure is experienced to be high, partly due to the increasing educational load, administrative tasks and fund-raising efforts. To address the issue of work pressure, we have hired additional staff for education, reviewed the different administrative processes and supported staff members in their personal development to better cope with work pressure. Internal communication has been addressed in employee satisfaction surveys and receives more attention. We adopt different ways to inform our staff on content and process like organised in the institutes and DRI's instead of purely through management lines.

We are confident that the further development of our Faculty Graduate School and the supervising teams will positively influence the duration of PhD-projects.

Funding is essential for our research output. We are very successful in acquiring funds (on a relative scale as scoring percentages gradually decrease). Success rates are in line with our main competitors. Raising the success rate is not easily achieved. We focus on supporting our staff in being informed on possibilities, evaluating internally proposals and shifting to getting more involved in the agenda setting of the writing of the draft programmes and building of and leading consortia. We also focus on the development of more substantial (in duration and size) Public-Private Cooperation programmes, which also addresses the shift of research funding to a higher TRL-level.

SWOT of the Faculty

Strengths	Weaknesses
• Strong cooperation within the Faculty and University on specific themes *Delft Institutes and Delft Research-based Initiatives play an important role* • Increasing number of personal grants *Excellence grants give more possibility to bring individual focus on research* • Strong interplay with industry and funding agencies *Approx 45% of funding of the faculty is acquired from external funds* • Excellent mix between fundamental and application-oriented research *Although peer appreciation in the different domains needs to be managed* • Excellent reputation and ranking in several disciplines *Our current reputation facilitates connections to (new) partners* • Excellent research infrastructure *An attractive but also expensive asset*	• Duration of PhD projects *Receiving much more attention these days, but still an important issue* • Work pressure is rising *Organisational tasks and educational obligations limit time for developing new lines of research* • Quality and availability of internal information *Individuals may feel not connected to (all) University and Faculty policies and developments* • Limited scientific debate among the disciplines working at the Faculty *Exploiting the strength of the unique multidisciplinary setting of the Faculty seems important.How to create a community and find time for exchange of ideas?*
Opportunities	**Threats**
• Societal challenges, sustainable development goals and world risks; search for resilient solutions *There is a great demand for civil engineering solutions to mitigate challenges or support solutions* • Research topics are very well covered by funding schemes *Within the Dutch and European funding programmes almost all of our research topics can be covered* • Possibilities to perform interdisciplinary research *Personal grants and science organisations' policies in general increasingly stimulate interdisciplinary research*	• More competitors for acquiring external funding *Especially relevant now: direct funding is needed more for education capacity due to larger student numbers* • Dependence on external funding for substance of research themes *Creating substance in the research programmes largely depends on acquiring external funding, with only a small chance of getting funds granted* • Agencies shift funding to higher Technology Readiness Levels *Detrimental for long-term fundamental programmes*

Experimentation and validation is in our DNA. Either lab measurements, performing field experiments or utilising living labs, the most appropriate approach(es) will be chosen. It is the Faculties strategy to actively support the initiatives concerning living labs; we expect that experimental set ups with respect to sensoring and data acquisition will dramatically grow in the coming year.
Finally, the most precious results of all our efforts is to 'deliver' many graduated MSc and PhD students to the market of private companies, public bodies and academia. They will contribute in the future to severe challenges like energy transition, climate adaptation and mitigation, urban complexities (smart cities), watercrises, sustianable CO_2 neutral processes and alike.

APPENDIX 1

Overview of and our reply to the recommendations of the previous Assessment Committee

Recommendation 1: Develop an attitude of a permanent search for innovation and excellence, which is a prerequisite for remaining a world leader. For small groups with a specific focus, it may be more difficult to achieve continuous renewal than for larger groups with a broader focus.

Implementation: We concentrated on appointing a new generation of professors, on adopting the tenure-track model for very promising younger faculty members and on achieving more connectivity within the Faculty. All in all, we succeeded in meeting the challenge posed by the AC.

Recommendation 2: Reinstate Integral Design as a core discipline of engineering research.

Implementation: Especially the Integral Design group within Structural Engineering, with a TU Delft-broad scope, was re-positioned and is currently consolidating. Connection to technical design has to be further developed. In the Hydraulic Engineering and Transport & Planning programmes we also implemented the integral design approach.

Recommendation 3: Strengthen coherence among the present research themes by considering interdisciplinary research topics, such as Asset Management and Economics.

Implementation: A connectivity programme was introduced in response to this issue. Asset Management was among the new approaches, connecting the Structural Engineering programme with the Water Management programme. A full time chair on Subsurface Engineering guarantees the liaison between the Hydraulic Engineering and Geoscience & Engineering programmes. We also intertwined the sections on rail traffic management and rail technology on educational programmes and interplay with third parties. Recently, with help of the Board of the University, we made room for a new chair and enforced a group on Urban Water Infrastructure. Our participation in TU Delft-broad Research Institutes grew substantially.

Recommendation 4: Develop a strategic plan at the institute level addressing these organizational weaknesses. It seems appropriate to reconsider the present group division of the institute, looking for larger, robust groups, with stronger coherence and better opportunities for interdisciplinary integration and innovation.

Implementation: Our recent Strategic Plan reflects the issues mentioned. In Structural Engineering, cohesion must still grow. We have therefore split the huge programme in two, to better manage a shared programme and build the communities.

Recommendation 5: Prepare a Succession Master Plan at the institute level.

Implementation: In every programme, we look for a balance in research areas and qualifications. Being open to top candidates without a detailed prescribed background is also a valid approach, especially to achieve better gender equality. The approach of not prescribing staff level (full, associate, assistant professor) worked out well.

Recommendation 6: Put more emphasis in the PhD training programme on the planning of the PhD project and the monitoring of related milestones.

Implementation: Due to the establishment of the University and Faculty Graduate School, awareness and results currently develop fast. A dedicated director has been appointed some years ago who interacts with Department Chairs and individual professors. A planning system facilitates extended monitoring on a structural basis.

Recommendation 7: Incorporate training of mathematical and programming skills in the education curriculum of the Faculty.

Implementation: A Massive Open Online Course (MOOC) was introduced to our freshmen to brush up their math level when omissions show up at their start at university. Programming skills (like MatLab, Python) are developed and these days intensively used in our renewed BSc programme. On the MSc level, a variety of programming tools is used and further developed (such as Diana, SWAN, SWASH).

Recommendation 8: Monitor and record the employment careers of alumni.

Implementation: Alumni are broadly involved in many activities, both by the faculty as via student bodies. A systematic CRM system to monitor careers of alumni is being developed by the central TU Delft organisation. In the large economic areas of the world, alumni "chapters" are active.

Recommendation 9: To stay at the top, the Delft Civil Engineering Institute should pursue stronger coherence in its research programme and stimulate stronger co-operation among its research groups and subgroups.

Implementation: This is an ongoing concern. In many subjects we really are at the top, for many years now. Especially in the water & climate cycles there is strong coherence. Also in the rail system, with two new professors in different programmes, several educational developments (a MOOC and Professional Education courses) and fast growing commitment of the Rail Authority. Safety, resilience, functional integration and sustainability appear to create strong coherence.

Hydraulic Engineering programme

1.1 Research area and objectives

1.1.1. MISSION

The mission of the Hydraulic Engineering programme is to educate world leading hydraulic engineers, train academic scientists and carry out world-class research in the key areas of sustainable infrastructure and nature-based solutions, renewable energy in the marine environment, dynamics of marine and inland water systems, climate and flood risk management. The Hydraulic Engineering programme enables sound assessment of hydraulic processes and thorough engineering of man-made interventions in support of safe and sustainable development of urbanised deltas, rivers, shorelines and coastal systems worldwide. To maintain our position as one of the world leading programmes, we carry out ground breaking fundamental and applied research. Our research topics are application-inspired with a permanent focus on their implications for nature, economy and society.

1.1.2 OBJECTIVES

The Netherlands, and in particular Delft, is an international hotspot where the full spectrum of hydraulic engineering is covered in depth, including first class research and education. The faculty of Civil Engineering and Geosciences is consistently ranked among the top public universities in the world; we make a strong contribution to this position and strive to maintain and improve our global position. The Hydraulic Engineering programme wants to maintain its key role in this realm by using its extensive worldwide network for application inspired, collaborative research with academia, research institutes and practitioners. Maintaining a high status in research and engineering and being influential at the global scale requires continuous efforts to innovate and advance research and educational programmes.

The approach of scientifically underpinning experience from practice by means of systematic investigation of the underlying physical processes has been very successful and has resulted in a productive and innovative research approach inspired by both natural processes and industrial applications, as for example reflected in the 'Building with Nature' concept. The programme aims to continue along these lines with a clear focus on future challenges associated with population growth, climate change, the energy transition and increasing environmental awareness. This can only be achieved through intensified collaboration with other disciplines, most notably ecology, spatial planning, governance and offshore energy in the Netherlands as well as abroad.

1.1.3 FOLLOW UP OF THE RESEARCH ASSESSMENT 2005-2010

In the previous research-quality assessment period (2005-2010), the sections of Hydraulic Engineering and Environmental Fluid Mechanics, which together formed the Hydraulic Engineering programme, were assessed separately. Both parts received "very good" to "excellent" evaluations. It was recommended to make better use of the expertise within the programme by encouraging stronger internal collaboration. It is therefore proposed that for the period 2011 – 2016, the Department of Hydraulic Engineering is assessed as one programme.

In the past years, a follow-up to the recommendations was given by initiating research projects with a broader multi-disciplinary scope, such as the Galveston Bay design project, programmes on Multi-functional flood defences, mega sand nourishments, and the many other research projects based on the building-with-nature philosophy. New staff members were hired e.g. with expertise in surface waves (Ad Renier), building with nature (Stefan Aarninkhof), ecology (Peter Herman), effects of climate change (Caroline Katsman) and infra-gravity waves (Tissier). Four cross-disciplinary research themes were formulated (see section 1.2.1), defining our joint research strategy.

Sinking seawater and rising sea level

Caroline Katsman

The Gulf Stream shutdown, plot of the movie 'The day After Tomorrow' is not as fantastical as it may sound, and could have grave consequences for sea level. 'Ocean currents influence sea level. This current is associated with a lower sea level in the North Atlantic and a higher sea level in the South Atlantic. If that circulation stops, sea level will tilt,' says Katsman. But in order to predict by how much sea level will rise and how fast you have to understand exactly what is happening to the current.

www.tudelft.nl/en/ceg/research/stories-of-science/sinking-sea-water-and-rising-sea-level/

1.2 Organisation of research

In the Hydraulic Engineering programme, research is performed covering the full spectrum of science, engineering and design. On the one side of this spectrum, research is performed to understand the physics of oceans, surface wave propagation, open-channel hydraulics, sediment transport, and their interactions with the natural environment and/or man-made structures. There is a strong emphasis on maintaining and further developing our modelling tools, such as the much used open source wave prediction models SWAN (swanmodel.sourceforge.net) and SWASH (swash.sourceforge.net), as a way to synthesise knowledge on these processes. Insights are provided by laboratory and field experiments as well as by computer modelling itself. On the other side of the spectrum, research is performed related to applications in coastal engineering, hydraulic structures and probabilistic design, dredging engineering, port and waterways, river engineering and offshore engineering. This ranges from the evaluations of beach nourishments to design guidelines for breakwaters and offshore structures. The research programme links the fundamental knowledge to integral applications by providing physics based modelling concepts that can be implemented in predictive computer models or design guidelines. This requires that the building blocks of knowledge, as obtained with laboratory experiments and analyses of physical processes, are integrated in modelling and design tools and evaluated in field observations. The nature of the processes studied makes the research results applicable and of interest to many regions around the world.

The integral approach of our research requires good interactions with neighbouring research fields within the Faculty of CEG, in particular with the Water Management and Structural Engineering programmes, but also with the geo-technical expertise in the Geoscience & Engineering programme. At the University level, the Faculties of Architecture, Mathematics and Technology Policy & Management are important partners.

1.2.1 INTEGRATION WITHIN THE PROGRAMME

The expertise present in the programme comprises the many specialised disciplines represented by the chair-groups relevant for the different application domains. Cross-cutting these administrative compartments, four research themes are identified that cover the greater part of the Hydraulic Engineering research programme, i.e.:

A. Sustainable infrastructure and nature-based solutions
B. Renewable energy in the marine environment
C. Dynamics of marine and inland water systems
D. Climate and flood risk management

These themes reflect future challenges and the attention that is paid to the integration of research, in order to provide results that are relevant for engineering and to address societal needs.

1.2.2 STAFF

In the evaluation period a substantial part of the senior staff retired, and new positions were successfully filled. This has resulted in a younger and more diverse group with complementary expertise

Table 1: Research staff 2011-2016 in the Hydraulic Engineering programme

	2011		2012		2013		2014		2015		2016	
Hydraulic Engineering	**#**	**FTE**	**#**	**FTE**	**#**	**FTE**	**#**	**FTE**	**#**	**FTE**	**#**	**FTE**
Scientific staff (1)	36	7,1	35	7,4	38	7,6	40	9,7	41	10,3	44	10,5
Researchers (2)	35	11,7	38	13,3	50	17,3	57	18,8	51	16,5	63	21,6
PhD candidates (3)	103	62,0	105	67,5	113	66,3	123	66,7	115	63,3	116	68,9
Total Research staff	174	80,8	178	88,1	201	91,2	220	95,2	207	90,1	223	101,0
Support staff	6	3,1	6	3,1	6	2,6	6	2,3	4	2,2	5	2,8
Total staff	180	83,9	184	91,2	207	93,8	226	97,5	211	92,3	228	103,8

(1) comparable with WOPI category HGL (full professor), UHD (associate professor), UD (assistant professor), tenured and non-tenured
(2) includes post-docs and temporary postgraduate researchers
(3) includes all PhD categories

Follow the pretty pebbles

Victor Chavarrias

Rivers meander: it's what they do. They make their way through the landscape twisting and turning as they flow. In the Netherlands a meandering river has become a rarity. 'Many rivers worldwide have been 'humanised'', says Victor Chavarrias. There are models which predict the flow of water and sediment. 'But in this case we also need models for the movement of mixtures of sediment of different sizes'.

www.tudelft.nl/en/ceg/research/stories-of-science/follow-the-pretty-pebbles/

Table 2: Contributors to core research themes of the Hydraulic Engineering programme

	m/f	H-index nov-2017	Sustainable infrastructure and nature based solutions	Renewable energy in marine environment	Dynamics of marine and inland water systems	Climate and flood risk management
Aarninkhof (prof)	m	16	●		●	●
Blom	f	9			●	
Bricker	m	9	●		●	●
Chassagne	f	10	●		●	
De Schipper	m	7			●	●
De Vries	m	6			●	●
Hofland	m	5	●			●
Herman (prof)	m	56	●			
Jonkman (prof)	m	18	●		●	●
Katsman	f	14			●	●
Kok (prof)	m	13				●
Labeur	m	7		●	●	
Lourens	f	6		●		
Metrikine (prof)	m	26		●	●	
Morales	m	9	●	●		●
Pietrzak (prof)	f	16			●	●
Taneja	f	4	●			
Reniers (prof)	m	27	●		●	●
Stive (prof)	m	36			●	●
Tissier	f	8			●	●
Tsouvalas	m	3		●		
Uijttewaal (prof)	m	24	●	●	●	
Van Prooijen	m	7	●			●
Van Rhee (prof)	m	6	●			
Vellinga (prof)	m	1	●			
Wang (prof)	m	24			●	
Winterwerp (prof)	m	30			●	
Zijlema	m	18		●		●
Zitman	m	8	●		●	

relevant for the defined research themes. Steps were made in the improvement of the gender balance (in Table 2) . Around one third of the fulltime staff members is female. There has been a deliberate choice in hiring on the one hand researchers with a strong focus on the fundamental physical processes and system knowledge, mainly in full-time tenure-track positions, and on the other hand researchers who work closer to the application field in engineering practice, mainly in part-time positions.

Table 1 contains an overview of the research staff 2011-2016, whereas Table 2 shows which researchers (staff) are main contributors to the different research themes. As may be noticed, Hydraulic Engineering has a relatively small research capacity (in terms of fte scientific staff) available in relation to the broad spectrum of research the programme is involved in. This is for an important part related to our successful MSc programme that attracts many students but results in a high teaching load for the staff. Nevertheless, the research output and its impact are substantial as reflected in the number of PhD students and publications.

1.2.3 FUNDING

The landscape of research funding is rapidly changing. The demand from society for research with clear

Table 3: Overview of the funding and expenditures of the Hydraulic Engineering programme

Hydraulic Engineering	**2011**		**2012**		**2013**		**2014**		**2015**		**2016**	
Funding:												
Direct funding (1)	3.494	56%	3.202	47%	3.387	52%	3.467	48%	4.278	55%	4.656	52%
Research grants (2)	146	2%	298	4%	1.199	18%	1.147	16%	1.430	18%	2.199	25%
Contract research (3)	2.380	38%	3.213	47%	1.671	26%	2.419	34%	1.888	24%	1.892	21%
Other (4)	260	4%	101	1%	281	4%	159	2%	195	3%	147	2%
Total funding	6.280	100%	6.814	100%	6.538	100%	7.193	100%	7.791	100%	8.893	100%
Expenditure:												
Personnel costs	5.032	75%	5.262	74%	5.532	80%	5.648	79%	6.147	79%	7.117	80%
Other costs	1.644	25%	1.838	26%	1.396	20%	1.516	21%	1.664	21%	1.754	20%
Total Expenditure	6.676	100%	7.100	100%	6.928	100%	7.164	100%	7.811	100%	8.872	100%

Note 1: Direct funding (basic funding / lump-sum budget)
Note 2: Research grants obtained in national scientific competition (e.g. grants from NWO and the Royal Academy)
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

utilisation potential (e.g. in the Top Sector 'Water' policy in the Netherlands and at the EU level) has emphasised the need to work more intensively with end-users. This has resulted in an even stronger involvement of the governmental and industrial organisations in our research programme. The programme has benefitted from these changes by using its leadership and network in hydraulic engineering research. This has resulted in a substantial increase in research funding (up to 25% of the total) acquired in competition at the national and European level. Nowadays, this includes the preparation of large, integral research proposals with a consortium of research groups from different universities complemented with industrial partners. Successful examples with the Hydraulic Engineering programme in the lead are found with STW (now NWO-TTW) Perspective programmes (Multifunctional flood defences, NatureCoast, All-risk) and STW-Water calls that are partially supported by the Top Sectors Water and Energy (Flow Slides, Long-term bed degradation in rivers) and national programmes such as FLOW (Far and Large Offshore Wind). The in-kind and cash contributions by private companies and knowledge institutes to such research projects have increased over the last decades up to 30%. This increased participation of industry in the second money stream has resulted in a slight overall reduction of direct industrial funding. With EU funding becoming increasingly important, the programme has the ambition to play a leading role in one or two large European research projects (H2020). The currently running H2020 project on innovative disaster resilience (BRIGAID) and the ERC project on near-shore monitoring (NEMO) are examples of this.

The programme encourages individual staff members to apply for personal grants as these reflect the quality of the individual researcher and allow for the shaping of research careers on the basis of innovative personal ideas that would not be realised within the larger collaborative projects. Successful examples are, Matthieu de Schipper (NWO-Veni), Caroline Katsman (NWO-Vidi), and Marcel Stive (ERC-Advanced).

1.3 Scientific quality

The programme is proud to be a global player on its major themes, ranging from e.g. applications in offshore wind to the worldwide use of our wave prediction model (SWAN) and the assessment of post-event flooding (from Katrina to Harvey). As the programme covers a broad range of research themes, expertise is present on almost every aspect and at different levels of aggregation. This results in a research climate in which researchers find experts next door, facilitating cooperation in teams of varying composition.

In addition to our visibility in the scientific community and in scientific publications, we link our research to the engineering and design practice, and educate our MSc and PhD students accordingly. This implies that societal relevance and research products other than publications are also considered relevant, typical examples of such output being numerical models, experimental tools and design guidelines (see table D1 in the appendix). This requires a good connection and communication with society and politics through participation in the public debate and collaboration with governmental organisations (ministry of public works, water authorities) knowledge institutes (Deltares, Marin, TNO) and industries (consultants, contractors and dredgers). Research projects are expected to be relevant for practitioners and preferably co-financed by industrial and governmental partners. This is not only restricted to the Dutch society and industry, as we consider the whole world as our playing field and much of the knowledge and tools we develop are generic and have wide ranges of application. Our MSc and PhD graduates find jobs in internationally operating companies and we receive, in increasing numbers, MSc and PhD candidates from all over the world.

1.3.1 RESEARCH THEMES AND MAIN RESULTS

Research theme A: Sustainable infrastructure and nature-based solutions

New approaches are developed for the design of sustainable hydraulic infrastructure, which aims to align primary functional requirements (for instance protection against flooding) with benefits for nature and society. Examples of such approaches are the design of a long-term coastal defence strategy for Texas (Houston – Galveston area), the development of sustainable land reclamation strategies along the Jiangsu coast in China (between Shanghai and Beijing) and the investigation of natural foreshores to guarantee safety of the Houtribdijk between Lelystad and Enkhuizen. The programme participates in these (inter)national initiatives with a focus on the development of integral solutions and research to enable evidence-based design. Newly appointed key players in this field are Bas Jonkman, Stefan Aarninkhof and Peter Herman.
These concrete cases can be considered real-world implementations of the concept of 'Building with Nature' that was further developed within the Ecoshape consortium. The implementation of the Sand-Engine mega nourishment and associated research programme (NatureCoast and STRAINS), the research initiatives around Marker Wadden and Western and Eastern Scheldt, the restoration of mangrove forests on Java (NWO-TTW Biomanco) and the Mekong Delta, are all examples of tangible research efforts with a strong focus on field measurements, aiming to develop the process knowledge needed to enable quantitative design of natural solutions. Collaborative research projects have been set up with Chinese and Vietnamese partners on coastal zone and estuarine management using soft, nature-based measures.
Besides field measurements, this theme relies on the use of experimental facilities to investigate processes and responses under extreme conditions. Laboratory experiments are used to evaluate novel approaches for assessing hydraulic loads (e.g. for the Dutch Afsluitdijk in collaboration with the Rijkswaterstaat and supported by NWO TTW (Dynamics project) and the stability of nature-based solutions under extreme wave conditions. With the employment of Dr. Bas Hofland, a leading expert on hydraulic loads on coastal structures, the programme has importantly strengthened its position in this field.

Key publications

- Wang, Z.B., Van Maren, , Ding,P.X., Yang, S.L., Van Prooijen, B.C., de Vet, P.L.M., Winterwerp, J.C., De Vriend, H.J., Stive, M.J.H, and He, Q (2015) Human impacts on morphodynamic thresholds in estuarine systems. Continental Shelf Research Volume 111, Part B, 1 Pages 174-183
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- Stive, M.J.F.; de Schipper, M.A.; Luijendijk, A.P.; Aarninkhof, S.G.J.; van Gelder-Maas, C.; van Thiel de Vries, J.S.M.; de Vries, S.; Henriquez, M.; Marx, S., and Ranasinghe, R., 2013. A new alternative to saving our beaches from local sea-level rise: the sand engine. Journal of Coastal Research, 29(5), 1001-1008. Coconut Creek (Florida), ISSN 0749-0208.
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- Saulo Meirelles, Martijn Henriquez, Ad Reniers, Arjen P. Luijendijk, Julie Pietrzak, Alexander Horner-Devine, Alejandro J. Souza, Marcel J.F. Stive Cross-shore stratified tidal flow seaward of a mega-nourishment. Estuarine, Coastal and Shelf Science, 2017.

Research theme B: Renewable energy in marine environment

We develop, investigate and test new methods of designing, installing and monitoring offshore wind turbines (OWTs). Research is conducted into the dynamic interaction of the OWTs with soil, waves and ice as well as into the environmental impact of the OWTs installation. Recently employed assistant professors Dr. Eliz-Mari Lourens, Dr. Apostolos Tsouvalas and Dr. Hayo Hendrikse perform ground-breaking research in the fields of monitoring of OWTs, reduction of environmental impact from wind farm installation and ice-structure interaction for OWTs to be installed in the Baltic Sea. Alongside offshore wind, the ocean energy is addressed within this theme.

With a main focus on tidal energy, such as the pilot concerning the deployment of Horizontal Axis Tidal turbines in the Eastern Scheldt barrier, we are also actively involved in research into the wave and thermal (OTEC) energy conversion and tidal power plants. Combination of wind and wave energy generators installed on floating platforms with the aim to generate CO_2-neutral synthetic fuel is an emerging dream-topic within our group.

Key publications

- De Oliveira Barbosa, J.M., Qu, Y., Metrikine, A.V. and Lourens, E.M. Vortex-induced vibrations of a freely vibrating cylinder near a plane boundary Experimental investigation and theoretical modelling, Journal of Fluids and Structures, 69 (2017) 382–401.
- Versteijlen, W.G., Metrikine, A.V. and van Dalen, K.N (2016) A method for identification of an effective Winkler foundation for large-diameter offshore wind turbine support structures based on in-situ measured small-strain soil response and 3D modelling. Engineering Structures Volume 124, 1 October 2016, Pages 221-236
- Tsouvalas, A. and Metrikin A.V. Noise reduction by the application of an air-bubble curtain in offshore pile driving, Journal of Sound and Vibration 371 (2016) 150-170.
- Hendrikse, H. and Metrikine, A.V. Interpretation and prediction of ice induced vibrations based on contact area variation, International Journal of Solids and Structures 75-76 (2015) 336-348.
- Corciulo, J., Zanoli, O and Pisanò, F. Transient response of offshore wind turbines on monpiles in sand: role of cyclic hydro-mechanical soil behaviour, Computers and Geotechnics, 83 (2017) 221-238.

Research theme C: Dynamics of marine and inland water systems

The complete water system, starting from inland waterways through ports, estuaries and deltas to coastal seas and deep oceans, is examined. Focus areas include the transition zones between the different water bodies where their dynamics overlap resulting in non-linear couplings affecting surface waves, (fine) sediment fluxes, salinity, temperature, river flow, tides and sea level, thereby shaping our rivers and coasts. Specific attention is given to the interaction of these processes with man-made structures while also their effects on water quality, ecology, navigability and coastal safety are important. It is obvious that effects of climate change are incorporated in the analyses. Given the vast range in physical scales, a key aspect of the research is the aggregation of small-scale processes to the larger-scale dynamics. To that end, we combine both laboratory and field experiments as well as remote sensing with the development of a suite of state-of-the-art numerical models that lead to an improved understanding of the water system dynamics and provide predictive tools that are being used in research, engineering and management worldwide. To accommodate the ever-increasing possibilities of computer modelling, new numerical techniques are continuously being developed. The tools developed for the predictions of free-surface waves, currents and river/coastal morphodynamics are considered as important output of our research activities. Particularly the in-house developed SWAN and SWASH models for the prediction of waves in a shallow environment are frequently used worldwide (> 2000 downloads in 2016).

Projects such as the STW Sustainable ROFI's (Pietrzak), the NWO Flocs and Fluff in the Delta (Chassagne) contribute to understanding the role of stratification on sediment dynamics. NWO projects related to the RiverCare "Perspective" programme and Top Sector Water call are carried out in close collaboration with consultants and the ministry of Public Works of The Netherlands and contribute to understanding of the long term morphological development resulting from human interferences in the river Rhine and its tributaries.

Key publications

- Blom, A., Viparelli, E. and Chavarrias Borras, V. (2016). The graded alluvial river: Profile concavity and downstream fining. Geophysical Research Letters, 43(12), 6285-6293. DOI: 10.1002/2016GL068898
- Vargas-Luna, A., Crosato, A. and Uijttewaal, W.S.J. (2015) Effects of vegetation on flow and sediment transport: comparative analyses and validation of predicting models. Earth Surface Processes and Landforms, Volume 40 , Issue 2 , Page 157
- Smit,P., Zijlema, M. and Stelling, G. (2013) Depth-induced wave breaking in a non-hydrostatic, near-shore wave model. Coastal Engineering Volume 76, Pages 1-16
- Volp, N.D., Van Prooijen, B.C., Pietrzak, J.D. and Stelling, G.S. (2016) A subgrid based approach for morphodynamic modelling. Advances in Water Resources Volume 93, Part A, Pages 105-117
- Carson, M., Köhl, A., Stammer, D., A Slangen, A.B. and Katsman, C.A.; (2016) et al. Coastal sea level changes, observed and projected during the 20th and 21st century. Climatic Change; Vol. 134, Iss. 1-2 : 269-281.
- Labeur, R.J. and Wells, G.N.; (2012) Energy stable and momentum conserving hybrid finite element method for the incompressible Navier-Stokes equations. SIAM journal on Scientific Computing; Vol. 34, No. 2, pp. A889–A913
- Cui, H., Pietrzak, J.D. and Stelling, G.S.; (2014). Optimal dispersion with minimized Poisson equations for non-hydrostatic free surface flows. Ocean Modelling; Vol. 81, pp. 1–12.
- Horner-Devine, A. R., J. D. Pietrzak, A. J. Souza, M. A. McKeon, S. Meirelles, M. Henriquez, R. P. Flores, and S. Rijnsburger (2017), Cross-shore transport of nearshore sediment by river plume frontal pumping, Geophys. Res. Lett., 44, 6343–6351.

Research theme D: Climate and flood risk management

We investigate the impacts of climate change and sea level rise on hydraulics, morphology and flood risks in the coastal zone and rivers. The work by Caroline Katsman has contributed to a better understanding of and the debates on the consequences of climate change to sea-level rise. The NWO SCENES Project B explores downscaling from climate models to the biogeomorphological evolution of Dutch Caribbean bays; Julie Pietrzak. Methods are developed by the group of Bas Jonkman and Mathijs Kok for the characterisation of current and future flood risks. This requires insight in hydraulics, failure mechanisms and reliability of flood defences, and in (novel ways to characterise) impacts of floods. Finally, "research by design" is conducted on various measures to reduce the risks: nature-based flood defences, storm surge barriers and innovative alternatives for dike reinforcements.

The programme is leading in the further development of quantitative methods for flood risk analysis. Over the last years, we have further developed several aspects of this approach, such as reliability-based updating based on survived loads, analysis of piping, loss-of-life models and optimisation approaches.

A recent new element includes the incorporation of nature-based flood risk reduction solutions (e.g. the NWO project BE SAFE; Bas Jonkman). Moreover, the approaches developed have been implemented in the Dutch national flood risk management policy and will provide a basis for future design. This is not limited to the Dutch conditions but extends to a number of delta's worldwide such as in Shanghai (funded by NWO; led by Jeremy Bricker), Vietnam and Galveston Bay in Texas.

Key publications

- Bouwer L.M. and Jonkman S.N. (2017) Global mortality from storm surges is decreasing. Environmental Research Letters, Accepted, in Press
- Frederikse T, Simon K, Katsman CA and Riva R, The sea level budget along the Northwest Atlantic coast: GIA, mass changes and large-scale ocean dynamics. J. of Geoph Res Oceans Vol. 122 Issue 7, 5486-5501
- Jonkman S.N., Maaskant B., Boyd E. and Levitan M.L. (2009) Loss of life caused by the flooding of

The Waterlab; facilities for education and research.

New Orleans after hurricane Katrina: Analysis of the relationship between flood characteristics and mortality. Risk Analysis, 29(5): 676-698. – Best paper award Society of Risk Analysis 2009

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- Schweckendiek, T., Vrouwenvelder, A.C.W.M. and Calle, E.O.F. (2014) Updating piping reliability with field performance observations. Structural Safety, 47: 13–23.
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1.3.2 FACILITIES

For research and education in hydraulic engineering, experimental facilities are indispensable as the complexity of the interactions between water motion and its boundaries, such as structures, sediment and vegetation cannot be properly demonstrated and analysed by other means. Additionally, the effects of the free surface in combination with turbulence put requirements to the size of the

Flood Proof Holland, experimental site for research and product development.

Table 4: Main categories of research output for the Hydraulic Engineering programme

Hydraulic Engineering	2011	2012	2013	2014	2015	2016
Refereed articles	64	74	91	71	97	127
Non-refereed articles (1)	0	1	0	2	2	1
Books	0	3	0	0	0	0
Book chapters	11	6	2	8	4	4
PhD theses	7	13	18	18	14	16
Conference papers	119	141	92	77	68	49
Professional publications (2)	16	21	20	14	22	14
Other research output (3)	48	76	169	144	106	74
Total publications	265	335	392	334	313	285

Note 1: Articles in journals that are non-refereed, yet deemed important for the field
Note 2: Publications aimed at professionals in the public and private sector (professionele publicaties), including patents and annotations (e.g. law)
Note 3: Other types of research output, such as patents, book reviews, editorships of books, editorships of journals, inaugural lectures, abstracts, designs / prototypes, appearances on radio or television, "populariserende artikelen" and other research output (internal reports, lectures).

facilities. Over the past decades, a gradual shift was made from studying down-scaled systems with respect to their behaviour to studying physical processes for the sake of understanding and parameterisation. The latter is induced by the rapid development of numerical models that allow for the integration of the various physical processes.

The programme makes use of a part of the Faculty's Water Lab in the Stevin III building. The facilities were recently re-arranged and upgraded allowing for a wide range of experimental research on free-surface waves, currents, sediment transport and motion of submerged structures in waves and currents. The size of the laboratory determines the possibilities, so choices have been made as to which facilities are important for future research. In relation to those choices, arrangements have been made with the neighbouring institute Deltares, in the form of a MoU, to develop a joint strategy with respect to facilities. This implies that relatively small-scale facilities dedicated to research on the more detailed physical processes are predominantly found at TU Delft, whereas the larger-scale integrated research is performed at Deltares. This arrangement guarantees the interaction and exchange of knowledge, personnel and equipment thereby keeping the Delft facilities at a high level.

The laboratory facilities are also used to test and maintain equipment needed for fieldwork, which has become an integral part of our research focus. In recent years, significant investments were made in the fast developing GPS-based measuring equipment for water motion, temperature, salinity and sediment content, and the deployment of these on versatile and flexible platforms including jet ski's and drones. This has enabled us to perform extensive novel field work in e.g. Meuse river, the Eastern and Western Scheldt as well as around the Sand Engine near Ter Heijde (e.g. the STRAINS and MegaPex experiment).

Under the umbrella of TU Delft, Valorisation Programme Deltatechnology & Water, the so-called Flood Proof Holland demonstration polder was established. This polder is used by product developers, engineers and knowledge institutes as a full-scale facility for testing innovative solutions for flood protection. The programme plays a key role in the use of the facility for education and research.
The computational infrastructure has recently been upgraded by purchasing a 240-node computer cluster. Additional bigger facilities are available through the National Computer Facility (NCF).

1.3.3 RESEARCH OUTPUT

The main research output indicators are summarised in Table 4. Following the assessment of 2005 – 2010, the programme has placed sharper focus on journal publications, and somewhat less on conference papers. Conferences remain an important plat-

SEAWAD: research into a sand engine for the Wadden Islands

Bram van Prooijen & Zheng Bing Wang

The sand engine, the artificially created expanse of sand off the coast of Zuid-Holland was developed to protect the Dutch coastline from erosion by making use of naturally occurring maritime currents. Bram van Prooijen and Professor Zheng Bing Wang research how such a sand engine can be used to protect coastline along the Wadden Islands in the future.

www.tudelft.nl/en/ceg/research/stories-of-science/seawad-research-into-a-sand-engine-for-the-wadden-islands/

Table 5: PhD candidates in the Hydraulic Engineering programme

Starting year	Female	Male	Total	Grad.	Grad. <= 4 yr		Grad. <= 5 yr		Grad. <= 6 yr		Grad. <= 7 yr		Not yet finished		Discontinued	
2008	3	9	12	12	1	8%	7	58%	12	100%	12	100%	0	0%	0	0%
2009	8	16	24	17	3	13%	8	33%	14	58%	17	71%	5	21%	2	8%
2010	6	13	19	12	1	5%	9	47%	10	53%	12	63%	5	26%	2	11%
2011	7	8	15	11	0	0%	11	73%	11	73%	11	73%	4	27%	0	0%
2012	3	5	8	1	0	0%	1	13%	1	13%	1	13%	5	63%	2	25%
	27	51	78	53	5	6%	36	46%	48	62%	53	68%	19	0%	6	8%

Note: This table includes Standard PhD candidates (with employee status) and Contract PhD candidates (without employee status, receiving external funding) conducting research with the primary aim/obligation of graduating, based on a 0,8-1,0 FTE contract. Please note that the data in the dark cells is incomplete. There are still PhD candidates active from those starting years that are able to graduate within the timeframe of the given years. Reference date: 1 januari 2017

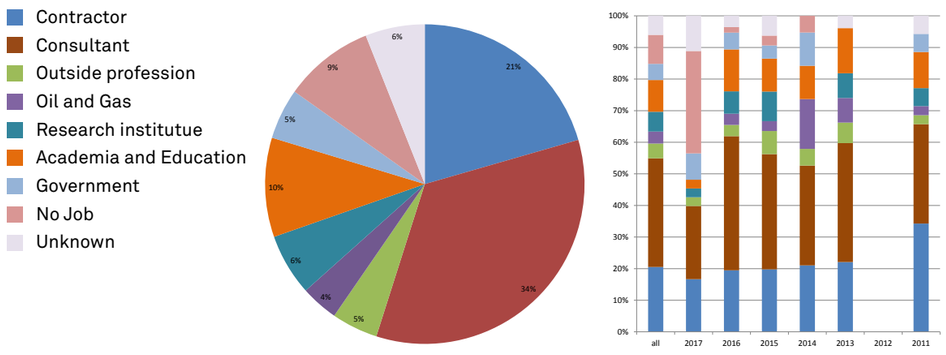
form for international networking and knowledge dissemination and exchange. It should be noted that much of the research output is incorporated in open-source modelling tools such as SWAN and SWASH (with yearly new releases) or in improvements of other tools owned by third parties such as X-Beach, Delft3D etc. The number of finalised PhD theses has grown to a stable number of 15 to 20 per year, which is also expected for the coming years.

1.3.4 PHD CANDIDATES

In 2010, the assessment committee concluded that the PhD/staff ratio was too high, and that the duration of the PhD projects became quite long. Based on this feedback, action was taken. In parallel, the TU Delft Graduate School was introduced, providing a well-structured educational programme and supervision protocol. For more information about the Graduate School see the general part of this self-assessment about the Faculty.

Over the last years, our acceptance policy of new PhD candidates with scholarships has been more formalised and more strict. Every new request for admissions is now discussed by the Board of the programme. The policy of the programme is to focus on acquiring new PhD candidates through funded well-defined projects and less through scholarships. The number of PhD candidates with external scholarships has decreased in most groups so that the PhD/staff ratio has become healthier. Through better defined research projects, a more systematic

Figure 1: Work affiliation of Hydraulic Engineering alumni (generations 2012-2017) in 2017. The data show that the majority of Hydraulic Engineering alumni find a job at an engineering consultant or contractor. The percentage unemployed after one year is well below 5%.



Continuously scanning the coast

Sander Vos

Hotel Atlantic in Kijkduin overlooks the North Sea. On its deserted roof a state of the art laser scanner is monitoring the beach every hour, 24/7. Sander Vos hopes the resulting data will provide insight into the restoration of the coast after a storm when part of the beach and fore dunes disappear into the sea. With the information provided by the scanner he and his TU Delft colleagues hope to become 'coastal weathermen' who will be able to predict exactly how the beach behaves after a storm.

www.tudelft.nl/en/ceg/research/stories-of-science/continuously-scanning-the-coast/

supervision and through the support of the TU Delft graduate school it is anticipated that the average duration of PhD projects will be reduced even more in the near future.

1.4 Societal relevance

Water infrastructure and flood protection are without any doubt of extreme importance for the society and economy of any country. In that respect, the programme contributes to society in many ways. First, we deliver more than 100 MSc students and around 15 PhD students annually, the majority of whom find jobs in their field of study at knowledge institutes, governmental organisations, dredging and construction companies and consultancy firms (see Figure 1). Second, most of our research is performed with support of and in interaction with the Hydraulic Engineering sector, embedding the research in the practice of Civil Engineering. This has influenced the orientation of the industry towards research and innovation, as can be seen in projects such as Maasvlakte 2, Sand Engine and Markerwadden. Various staff members play an advisory role in national (governmental) committees.

1.4.1 RESEARCH AND ACHIEVED SOCIETAL IMPACT

The Sand Engine is considered as a demonstration project for the Building with Nature concept that is now also being used in the design of Markerwadden. This promising new technology finds its way in industry through the Ecoshape consortium. New nature-based solutions are found in research projects related to e.g. the restoration of mangrove coasts in Java (Indonesia) and the Mekong Delta. The knowledge generated about flood risk analysis has been implemented in the standardised tools developed in the national flood risk assessment project (VNK). The utilisation of knowledge and expertise is also visible in strategic cooperation related to the Top Sector Water, and in active collaborations with various groups of Deltares and departments of Rijkswaterstaat on flood risk and hydraulic engineering. This ranges from participating in sounding boards, discussions and brainstorm sessions, to the joint use of facilities and development of measurement equipment and development of numerical tools. Senior staff members in the programme are often present in the national and international media and in the public debate. Examples are the debates on flood risk management in the Netherlands and worldwide (also New York and Texas), and on coastal management and climate adaptation.

Contributions at the national level include:

- New safety standards for flood defences, implemented in the year 2014
- National discussions on strategic interventions: Rijnmond / Rotterdam, Markermeerdijken, storm surge barriers and the coastal zone.

International activities in this field include:

- Texas, Houston, Galveston area (book published, active academic exchange on future flood risk reduction). After Sandy by means of an online opinion article in the NY Times.
- Members of the programme are frequently asked to provide expertise by means of reviews and consulting reports. This contributes to the overall funding and utilisation and inspiration of research. Examples are consultancy projects for Rijkswaterstaat, engineering firms, international governments (USACE, USBR), insurance firms (FM Global) and groups of local business in Texas.

In developing countries, contributions have been made through capacity building and joint research on flood risk. Examples are trainings and collaborations with Vietnam, Mozambique, Thailand and Indonesia of which the aim is to find tailor-made flood-risk reduction solutions for developing countries. The membership of Marcel Stive and Han Vrijling to the Myanmar IWRM Committee (chaired by former Minister Veerman) is worth mentioning in this respect.

The programme has developed the SWAN numerical wave prediction model that has approximately a thousand users worldwide. Furthermore, the coastal morphology model XBeach was co-developed with Deltares and is seen as an important numerical tool for research and design. Other contributions pertain to the SWASH, H2Ocean and FinLab hydraulic models that were developed 'in house', and to externally developed models like the Deltares model Delft3D.

The programme has also initiated various research projects related to offshore wind and tidal energy production. These directly contribute to the optimisation and further development of ongoing implementation of renewable energy production. Transfer of knowledge and expertise is also realised

BRIGAID: Solutions for extreme climate events

Bas Jonkman

Climate scientists are predicting an increase in droughts, floods and other extreme weather events as a result of continuing global warming. BRIGAID (Bridging the gap for Innovations in Disaster Resilience), an ambitious programme initiated by a partnership of European universities, research institutes and businesses, is aimed at finding innovative ways of coping with the increased likelihood of natural disasters of this kind.

www.tudelft.nl/en/ceg/research/stories-of-science/brigaid-solutions-for-extreme-climate-events/

Dutch television
"100 years of floods"

in start-up/spin-off companies that emerged or have strong ties with the Hydraulic Engineering programme. Examples are: Jongejan RMC, a company specialized in developing flood risk tools; SHORE Monitoring and Wavedroid, companies specialised in mobile measuring and surveying techniques; aQysta, a start-up developing a flow-driven irrigation pump.

Media attention

Where possible, the Hydraulic Engineering programme contributes to informing a broad audience about its activities. Examples on Dutch television are:

- An item of about 25 minutes on the research dedicated to the Sand Engine, "De Kennis van Nu" dd. 2-11-2014 www.npo.nl/de-kennis-van-nu/02-11-2014/VPWON_1229351
- An item of about 15 minutes on free-surface waves in "Klokhuis" dd. 29-8-2012 www.hetklokhuis.nl/tv-uitzending/2024/Golven.
- Marcel Stive explained the Sand Engine on the BBC news (broadcasted December 4 and 8, 2015) and the Australian Broadcasting Cy (www.abc.net.au/lateline/content/2015/s4358916.htm?site=melbourne).
- Bas Jonkman played a central role in a 50-minute programme on "100 years of flooding" (Jan 13, 2016): www.npo.nl/nos-100-jaar-droge-voeten/13-01-2016/16act0113Droge.

1.4.2 EMBEDDING IN THE FIELD

The historic ties with Rijkswaterstaat and Deltares have resulted in a research culture that naturally connects to these organisations and water-related issues in the public domain. Additionally, large offshore and dredging companies as well as the smaller, specialised consultants and start-ups have become increasingly aware of the importance of innovation and knowledge development of which the ECO-SHAPE consortium is a good example. This positions the programme firmly at one of the corners of the 'golden triangle', representing the hydraulic engineering sector, together with governmental organisations and private companies. The importance of this position is illustrated by the successful acquisition of novel research projects. In almost all projects governmental and industrial partners have a vested interest, including substantial financial contributions. The involvement in research projects of non-academic partners is not our only connection with the hydraulic engineering sector: the exchange of staff as guest lecturers, part time (assistant, associate, full) professors and participation of scientific staff in advisory committees provides further real-world inspiration for our research and education. Many research projects are executed in strong collaboration with other universities, in particular with the universities of Twente, Wageningen and Utrecht, and institutes like UNESCO-IHE, NIOZ and MARIN, thus combining strengths and pursuing complementarity.

The above-described embedding is not only limited to The Netherlands, as all researchers are active in the various international research networks, such as IAHR, AGU, PIANC etc. In addition, bilateral networks between research groups have been built with upcoming countries in South-East Asia (Vietnam, China, Myanmar) and other regions with specific flooding issues (New Orleans, Houston/Texas). This also concerns joint educational programmes such as Erasmus Mundus and the joint degree programme with NUS, Singapore.

The turbulent waters of the Eastern Scheldt

Yorick Broekema

Whenever there is a problem with the Eastern Scheldt storm surge barrier, the Dutch get worried. The last time the barrier made the news was in 2013, when the stability of the barrier's foundation protection was compromised. What was going on? 'Very strong currents can cause deep holes to appear in the Eastern Scheldt seabed. This increases the chances of damage to the foundations of the barrier,' explains PhD Yorick Broekema. Now the stability of the barrier is no longer an issue. It's my job to look for an ecological and sustainable solution so the people of Zeeland don't get their feet wet,' Broekema says.

www.tudelft.nl/en/ceg/research/stories-of-science/the-turbulent-waters-of-the-eastern-scheldt/

Royal Dutch Water network thesis price.

Marcel Stive receiving declaration Nighthood in the order of the Dutch Lion.

1.4.3 RECOGNITION

The Hydraulic Engineering programme contributes significantly to the international esteem of the TU Delft through the historical contributions to the design flood defence systems but also by more recent innovations such as the sand engine and the building with nature concept. The high position in international rankings on water-related subjects, such as in QS and Shanghai, is for an important part based on this reputation.

Researchers in the programme are frequently asked for and involved in several national and international networks and advisory groups. These include the expertise network on flood protection ENW (Stefan Aarninkhof, Matthijs Kok, Bas Jonkman, Astrid Blom, several emeritus professors) and (since recently) the national water advisory committee ACW (Bas Jonkman). Professors Stive and Vrijling (retired) have been members of the National Delta Committees advising the government on future strategies regarding flood defence and drought mitigation. With contributions to research, projects companies and governmental organisations commit themselves not only to financial support, but also to personal involvement through participation in user panels, demonstrating the importance of the research for those organisations. These contributions are becoming increasingly important as part of the Top Sector Water approach.
We consider the co-financing of chair groups and the appointment of scientific staff as a recognition of the importance of our work for the sector. For example, the flood risk chair of Mathijs Kok is sponsored by Rijkswaterstaat, the chair of sediment dynamics of Han Winterwerp is sponsored by Deltares, and the chair of Ports and Waterways of Tiedo Vellinga is sponsored by the Rotterdam Port Authority. In kind, staff has been provided by Deltares for about 2 fte, and a similar total amount of fte is provided by several engineering firms.

It is rewarding to see that a large part of our PhD and MSc graduates find jobs in the practice of hydraulic engineering and research and that many find leading positions in defining strategies for research, innovation and development. It is interesting that in recent years, also international MSc and PhD students found positions within the Dutch water sector and beyond (some examples are: Qian Ke, Miguel Angel Lucas at Deltares, Haiyang Cui at Shell).

Public professional prizes:

- Marcel Stive has won the 2015 International Coastal Engineering Award, ASCE, the 2015 International Coastal Sediments Award, and received an honorary doctorate from the University of Lund Sweden (2012).
- Students are regularly awarded prizes for their theses e.g.: Jakob Maljaars (UfD-Damen Award, best BSc thesis 2014), Erik van Berchum (Koninklijke Nederlandse Waternetwerk-Scriptieprijs 2015) Chris Keijdener (KIVI-NIRIA prijs Offshore en Baggertechniek 2013).
- Vrijling 2012: Knighthood in the Order of Oranje Nassau.
- Stive 2013: Knighthood in the order of the Dutch Lion.

1.5 Viability

In the assessment period, the programme has seen a number of changes as several staff members retired and were succeeded by younger staff members. This has happened at all levels, from assistant to associate and full professors. Successors have brought in new skills and specialisms opening up opportunities for innovations that have become possible through multi-stakeholder, multi-functional projects such as Building with Nature in riverine, estuarine and maritime environments, and by the availability of new observational techniques and increased computer capacity. Investments have been made to strengthen our input related to the role of ecology and field work in hydraulic engineering, for example with the appointment of an expert on ecohydraulics (Peter Herman) and expansion of our measurement activities in the field. The research topics related to the application fields of ports, waterways, rivers and hydraulic structures receive specific attention in order to keep sufficient capacity for the growing numbers of students, and to keep the expertise at a high level despite the upcoming retirement of senior staff. The viability and future development of the four research themes described earlier are addressed below.

Research theme A: Sustainable infrastructure and nature-based solutions
The theme of 'Sustainable infrastructure and nature-based solutions' enjoys broad interest amongst government, engineering and research parties. Dutch industry has decided to continue Ecoshape funding to at least 2020, the topic prominently features on national (NWA 'Blauwe Route', NKWK) as well as international research agendas (EU Horizon2020), and the Building with Nature programme is paralleled by many similar initiatives worldwide (USACE Engineering with Nature, PIANC Working with Nature, others). The new, nature-based concepts are broadly embraced and full-scale applications will generate a wealth of new research questions, particularly to enable evidence-based design of nature-based solutions.

Many of these research initiatives will be linked to real-world infrastructure projects. Recent employment of PhDs on the Hondsbossche Duinen coastal reinforcement project and the Houtribdijk sandy foreshore project confirm this trend. This development aligns with one of the ambitions of the 'Beter Leren Keren' advice of the Expertise Network Water Safety (ENW), which states that dedicated monitoring and research programmes on real-world hydraulic infrastructure projects can be a driver for cost-savings and other benefits on future projects. The programme has adopted a leading role in making this happen.

Research in this field increasingly relies on the availability of high-resolution field measurements. With the onset of cloud-based tools like Google Engine, a wealth of satellite data has become available that offers unprecedented opportunities for studies on long-year natural dynamics of deltas, rivers and coasts. Key parameters include shoreline dynamics and vegetation coverage. Large-scale, global observations are supported by local, integral measurement sites, which allow for in-depth coastal research through permanent, simultaneous collection of in-situ and remote-sensing data, fused with numerical models. The programme is in the lead of the Dutch ICON.NL initiative, which forms part of the newly established 'International Coastline Observatory Network' (ICON). This initiative has readily inspired new research on sensor development, such as the application of drone technology for rapid assessment of nearshore processes.

Research theme B: Renewable energy in marine environment
The ambitious targets set recently by the Dutch government to accelerate the energy transition will spawn a number of research initiatives to develop and optimise systems for harvesting sustainable energy. From a hydraulic engineering perspective, interesting new developments concern offshore wind farms and tidal turbine arrays which both pose challenges with respect to their construction as well as their impact on the nearby water environment. It is the combination of expertise in offshore engineering by Andrei Metrikine (bottom founded structures) and environmental fluid mechanics by Robert Jan Labeur (waves, currents, sediment transport) that helps understand the various interactions such as between the motion of the fluid and the structure, erosion processes in the wakes of turbines and structures, and the impact of pile installation on the environment. In addition collaboration by environmental engineeringJulie Pietrzak and offshore engineering by Jeroen Hoving with Berend Kleute of BLUERISE is investigating deploying an OTEC facility off Curacao.

Cooperating with the industry and the Dutch government, the Hydraulic Engineering programme has emerged in this new playing field as an important partner in large research programmes (FLOW, Euros). The work that is currently ongoing, made possible through several (NWO) research grants, secures our position in this domain, which is likely to grow during the next decade. The combination of fundamental knowledge, state-of-the-art modelling tools, good laboratory facilities as well as ample experience in the field, brings the programme in the position of taking a leading role here.

Research theme C: Dynamics of marine and inland water systems
Already for many decades, understanding of the physical processes that govern the dynamics of water systems has been a major focus for the Hydraulic Engineering research programme. This has resulted in knowledge of the marine and inland systems, which has accumulated in numerical models such as SWAN, SWASH, FinLab, Delft3d, and X-Beach. This theme therefore forms a backbone of process-based knowledge, supporting the other themes with tools and techniques.

The successful research on surface wave prediction modelling will be continued: wave physics and associated transport processes receive renewed attention through the appointment of Ad Reniers as well as through the further development of the SWAN model led by Marcel Zijlema.

The programme takes a leading role, in the person of Astrid Blom, in defining the long-term research programme for rivers. In this programme, supported by the Dutch Ministry of Infrastructure and Water Management, a framework for river research is developed that addresses the knowledge gaps that need to be filled by fundamental understanding of river morphodynamics. The growing research group on river hydraulics and river morphodynamics will therefore grow further in size and impact.

The earlier mentioned importance of ecology in hydraulic engineering has made us decide to increase our efforts in this field, particularly concerning the fundamental biotic and a-biotic interactions. With support of e.g. the World Wildlife Fund and Wetlands International research projects on mangrove coastal protection, and studies on interactions between vegetation, water motion and sediment transport have started and new projects are in preparation. The importance of ocean circulation, stratification and associated transport processes at the global scale are well recognised. With the recent appointment of Caroline Katsman, research capacity in this field is expanded, particularly with the team she has formed around research on the Atlantic circulation.

Research theme D: Climate and flood risk management
This theme addresses one of the grand challenges for the coming decades, for The Netherlands and the rest of the world. The programme combines strong fundamental knowledge with a strong focus on application and valorisation in this field. A very good network of Dutch and international academic peers and end-users is in place. For example Julie Pietrzak and Caroline Katsman carry out innovative multi-scale research in the NWO SCENES project (PI Henk Dijkstra UU) which focusses on climate change impacts on Dutch Caribbean Islands. The programme has initiated (largely funded) research programmes for coastal flood risk management in Japan, Shanghai (funded by NWO; PI Jeremy Bricker) and Texas.

The viability of this theme is clearly demonstrated by two recent major projects that have been awarded in this field: on behalf of the Hydraulic Engineering programme, Kok coordinates the project 'All Risk' granted by the NWO-TTW (formerly STW) Perspective programme. It focuses on research related to the Dutch flood protection programme and represents a total value of 4.6 M€ and 18 positions of which about half at TU Delft. The EU-funded project BRIGAID (coordinator Bas Jonkman; 24 partners) focuses on the development and implementation of innovative technologies for the reduction of risks of floods, droughts and extreme weather in a changing climate. The project is realising pilots and monitoring programmes in locations such as Antwerp, Bucharest, Delft and Venice.

Within TU Delft, an integral and multidisciplinary approach for risk reduction in deltas is being developed, in a collaboration with colleagues from the Faculties of Architecture and Policy and Management of Technology. Actual events and cases, such as the collaboration with Houston / Texas[1], are used as a basis to learn from disasters and develop a "research by design" approach for risk reduction in deltas.

All these programmes contribute to the development of a knowledge portfolio on climate-proof flood-risk management. As a combination of hard and soft (nature-based) interventions is required, there is a strong link with theme A ("sustainable infrastructure and nature based solutions").

1.5.1 BENCHMARK: IMPERIAL COLLEGE[2]

In order to reflect on our operation and strategy we paid a visit to the sections of Fluid Mechanics and Environmental and Water Resources at Imperial College, London. Despite the many differences between the research groups at both universities, they share an awareness for quality and the need for prolonged efforts to stay an esteemed top-ranked group. It is clear that high-quality research and education require continuous attention at all levels in the organisation. Much depends on the financial structure at the national as well as university level, the recruitment of staff, the freedom and opportunities to excel, and a transparent methodology to evaluate quality of performance of individual staff members and of the research group as a whole. For a department of civil and environmental engineering, good connections with industry are of great importance from the perspective of application-inspired research and the acquisition of research funding as well as providing relevant education for MSc students and PhD candidates. These aspects have a similar effect on the education and research programmes at Imperial College as at our Department, and determine both the relevance and impact of the group's research. As a consequence, the research themes and approaches of Imperial College and TU Delft show much overlap.

The most remarkable differences are found in the time that is spent by the research staff on teaching and acquiring research funds. At Imperial College, teaching is estimated at 100 hours per year, less than 20% of what our Hydraulic Engineering staff spend on teaching. As part of the PhD research funding is provided via large programmes based on the institute's reputation, the time spent on proposal writing is substantially less, allowing much more time for the research and research supervision. Creating these conditions at TU Delft would require a major change in the organisation of workload and distribution of budgets at institutional and national level.

1.5.2 SWOT

The programme has performed a self-assessment and has identified the following strengths, weaknesses, opportunities and threats.

The weaknesses and threats are addressed as follows:

- The duration of PhD projects is expected to be reduced due to a more strict intake policy, the systematic approach of the Graduate School and the systematic appointment of supervision teams;
- The excesses of increased workload in education (specifically in offshore and general hydraulic engineering) are accommodated by hiring additional staff at various levels.
- An implementation plan has been made for the ports and waterways group for the coming years, addressing the future of the group. An important role will be played by the new part-time professor of ports and waterways who will be recruited early 2018.
- New collaboration programmes with Rijkswaterstaat and Deltares for the period 2016 - 2020 are in preparation to renew and improve the collaboration and strengthen the financial position of the programme.

1.5.3 STRATEGY FOR THE FUTURE

The programme strives to stay at the forefront of hydraulic engineering research by further developing fundamental knowledge of governing processes that are relevant for practice and society. The research themes that we defined help us in focussing on the relevant research challenges and in bringing together the important research disciplines. This requires a strong link with the various parties in the water sector, from industry to government.

1. After the floods of Houston due to Hurricane Harvey in September 2017, a multidisciplinary fact-finding research mission has been performed. A research report has been published and a seminar has been held in October 2017 with about 80 participants to discuss the findings.

2. The Departments of Water Management and Hydraulic Engineering combined their benchmark and visited Imperial College together.

SWOT of the Hydraulic Engineering programme

Strengths • The group was been rejuvenated with enthusiastic and highly qualified new professors and young promising staff. • Strengthened cross-links within the programme in research projects. • Good research portfolio through 2nd money stream projects. • Excellent partnering with water authorities, consultants and contractors in research programs ("Top Sector Water" approach successfully implemented) • High-quality and efficiently organised research infrastructure, both internally and externally (labs, flood proof polder, field sites, computer cluster).	**Weaknesses** • Duration of PhD trajectories is in many cases more than four/five years. • Understaffing of several sections in combination with strong growth in the number of BSc and MSc students has led to a high workload. • The expertise on ports and waterways is concentrated in a small group of mainly part-time temporary staff. This makes this line of research vulnerable.
Opportunities • Renewed and stronger connections with Rijkswaterstaat, Deltares and industry are emerging and will contribute to joint research programmes. • Hydraulic engineering in general addresses some of the "grand challenges": world-wide economic growth and urbanisation asks for smart and sustainable solutions in relation to water availability, energy supply and flood risk management. Our existing networks in Vietnam, China, Myanmar and the US provide opportunities to play a key role in the development of a water infrastructure at an unprecedented scale, making use of modern methods and lessons learned from our long-lasting experience.	**Threats** • It is not always easy to attract good PhD students and staff in competition with industry. • The unique position of the group depends on a delicate balance between fundamental research inspired by and applied to the engineering practice. Being able to keep this balance strongly depends on university policies, funding schemes and the role played by Rijkswaterstaat and Deltares. So far, conditions have been favourable for executing our research programmes, but the group is vulnerable to changes in these conditions. • The large and still increasing number of MSc students (of the order of 100 students/year) limits the time staff members have available for research activities.

At the national level, stronger ties with industry and the ministry of public works will result in consortia that collaborate in so-called 'living labs', with funding from private companies, government and the Dutch research council. The programme will thus play a significant role in Markerwadden, Kustgenese, the National research programme on Rivers (NKWK), as well as in the large offshore wind consortium GROW. International networks will be further strengthened in the various constellations of researchers. Examples are found within the projects BRIGAID and ICON mentioned earlier.

With the rejuvenation of the research staff with high-quality researchers, engineers and teachers, new networks will be formed and new projects will be submitted, initiated and executed (e.g. All-risk, BRIGAID) in the coming period. This renewed energy provides opportunities to explore new fields, making good use of past achievements.

The successes in acquiring second money stream funds motivate us to continue in that direction. Unfortunately our recent two large STW Perspective programme proposals stranded in the final round: i.e. Salt intrusion through surface waters (Julie

Pietrzak; SALTI, 3.1M€), and Morphodynamics of tide-dominated basins (Stefan Aarninkhof; ECLIPSE, 5M€). Nevertheless, the established networks and identified research topics will be converted into either new submissions to the Parsectief programme, or into new research proposals with a somewhat smaller but hopefully stronger focus.

More attention will be given to monitoring and experimenting in the field. Investments in field equipment and technical support should result in a more coherent and systematic monitoring approach as regards to coastal, estuarine and river observations both from air-borne, satellite as well as in-situ measurements. As knowledge of biotic and a-biotic interactions is important to understand, the system dynamics collaboration with ecological institutes such as NIOZ will be intensified. Also, the appointment in our programme of a renowned ecologist,Peter Herman, allows us to pay more attention to the linkage of ecology to hydraulic engineering processes, facilitating the further development of the 'Building with Nature' methodology.

Transport & Planning programme

1.1 Research area and objectives

1.1.1 MISSION

The mission of the Transport & Planning (T&P) research programme is to achieve top-level fundamental research that contributes to a more efficient and robust design and reliable operation of transport systems that meet mobility demands and respect scarce resources of land, environment and people. T&P research has a clear perspective to society-driven applications by using a multidisciplinary approach. Professionals from transport and planning practice are actively involved in the development of research projects and dissemination of research results. Finally, the T&P mission includes contributing to top-level MSc and PhD education in transportation.

1.1.2 OBJECTIVES

The objectives of the programme are as follows:

- T&P aims to conduct its research with a perspective on multiple transport modes and multiple user classes. The research uses rigorous quantitative approaches and is based on original empirical data.
- T&P aims to conduct its research into fruitful and promising topics and approaches along its four core application areas: Cooperative and Automated Driving, Active Mode Mobility, Coordinated and Cooperative Network Traffic Operations and Management and Reliable Multimodal Transport Systems.
- T&P aims to intensify the use of data collection and analysis tools, as a sustained basis for solid and innovative research results.

1.1.3 FOLLOW-UP OF THE RESEARCH ASSESSMENT 2005-2010

During the research assessment 2005-2010, T&P received the highest marks in all assessment categories. The committee recommended T&P to continue to build on its research strategy that had been successful thus far, namely to combine striving for the highest scientific standards whilst taking into account application in real-world situations. The committee endorsed the T&P programme's aims

to further increase the number of PhD positions and attract highly talented PhD researchers, to increase T&P's scientific impact and visibility by further increasing its research output in scientific journals and to take a leading role in (the organisation of) scientific conferences and the editorial boards of leading journals.
These goals were successfully met in the assessment period 2011-2016, as evidenced by the following: In the 2017 Shanghai Global Rankings of Academic Subjects, TU Delft was ranked world 1st in Transportation Science and Technology over the period 2011-2016. An analysis of the underlying journal publication data reveals that T&P is the major group at TU Delft to contribute this position. The TU Delft top 10 of staff members ranked by the number of publication co-authorships features seven T&P staff members with Prof. Serge Hoogendoorn ranking 1st. An analysis of Transport research publications over 2007-2016 yields TU Delft as the world 1st in productivity and 2nd in impact.

In line with the recommendation of the 2005-2010 committee, we developed a master plan for the replacement of retiring staff members to strengthen our scientific position, focusing on scientific and educational excellence. The master plan entailed the recruitment of several tenure-track assistant professors.

- The application area Coordinated and Cooperative Network Traffic Operations and Management was reinforced by appointing tenure-track assistant professors in Network Wide Traffic Operations and Management (Victor Knoop) and Geometric Design of Roads and Railways (Haneen Farah). Hans van Lint was promoted to full professor of Traffic Simulation and Computing in the prestigious Antoni van Leeuwenhoek programme.
- The application area Reliable Multi Modal Transport System field was strengthened with a new part-time full professor Regional Transport Planning Models (Erik de Romph) and tenure-track assistant professors in the fields of Regional Transport Models (Adam Pel), Management of Public Transport Systems (Oded Cats), Multimodal Transport Networks (Goncalo Correia) and Assessment of Smart and Sustainable Transport Systems (Dimitris Milakis). The topic of Freight and Logistics was strengthened with a part-time professor Freight Transport and Traffic Networks (Rob Zuidwijk), whilst 3 researchers (Bart Wiegmans, Jaap Vleugel and Milan Janic) joined the T&P programme with expertise in freight transport, transport economics and air transport.
- The application area Cooperative and Automated Driving was reinforced by appointing a tenure-track assistant professor on control of traffic flows with automated vehicles (Meng Wang).

Extensive investments in data collection resulted in the purchase and/or use of GPS, Wifi/Bluetooth and UAV data collection systems, a Toyota Prius instrumented vehicle and the Delft Integrated Travel and Traffic data laboratory (DiTTLab). All of these have already been extensively used in research projects and provide an excellent basis for future research.
T&P staff members have taken a leading role in developing cooperation within TU Delft: Prof. Bart van Arem as director of the TU Delft Transport Institute, Prof. Hans van Lint as director of the MSc programme Transport, Infrastructure and Logistics, Prof. Serge Hoogendoorn as PI Mobility in the Amsterdam Institute of Advanced Metropolitan Solutions (AMS) and Prof. Rob Zuidwijk as PI Metropoles and Mainports in the Leiden-Delft-Erasmus federation.

In line with the recommendation of 2005-2010 we further strengthened the cooperation between T&P and other disciplines. Cooperation with the TU Delft Faculties of Technology, Policy and Management (TPM), Mechanical, Materials and Maritime Engineering (3mE), and Electrical Engineering, Mathematics and Computer Science (EEMCS) has been particularly fruitful in the fields of DiTTLab (see 1.3 Lab Facilities), Automated Driving, Freight Transport and Logistics and Active Modes. Within our own Faculty of Civil Engineering and Geosciences (CEG), collaboration has intensified with Hydraulic Engineering (ports and waterways, nautical traffic models, flood risk management and evacuation planning and management), Geoscience and Remote Sensing (lane level positioning), and Structural Engineering (road and railway engineering, integral management).

1.2 Organisation of research

1.2.1 CORE APPLICATION FIELDS

During the assessment period, the research themes of T&P have been carefully redefined into four coherent core application fields, having identified the main knowledge gaps and most prominent research challenges, while considering urgent societal and technological trends that affect the transportation system (e.g. urbanisation, ICT, automation, electrification, and the related transitions, etc.) as well as the prevailing and future policy objectives (safety and security, throughput, reliability).
These core application fields (themes) are:

A. Coordinated and Cooperative Network Traffic Operations and Management (including emergency situations);
B. Reliable Multimodal Transport Systems;
C. Cooperative and Automated Driving;
D. Active Mode Mobility.

The core application fields are connected by the overall T&P strategy aimed at gaining a deep understanding of the traffic and transportation system and all the complex interactions it entails, via theory development, modelling, advanced simulation, etc.

1.2.2 STAFF

Table 1 provides an overview of the research staff. The appointment of new tenure-track assistant professors and retirement of scientific staff member resulted in a slight increase in the number of scientific staff, with a considerable decrease in the average age of the scientific staff. As some of these replacements overlapped, the total scientific staff size was slightly larger in the period 2012 - 2014. The female-to-male (f:m) gender ratio in scientific staff increased from 10% : 90% to 18% : 82% over the assessment period. A strong increase in the number of PhD candidates was realised on the basis of the successful acquisition of several large research projects.

During the assessment period, Prof. Bart van Arem carried integral responsibility for research (and education) of the Department of Transport & Planning. Strategic decisions were made in the bi-weekly meetings of the General Board ('Algemene Leiding' or AL in Dutch). The AL comprises all full professors, the executive secretary, the education coordinator and representatives from the MSc students and PhD researchers.

The main Human Resource responsibilities for the staff members were divided (roughly) along the core application fields over Prof. Bart van Arem (Reliable Multimodal Transport Systems and Operations, Cooperative and Automated Driving) and Prof. Serge Hoogendoorn (Network Traffic operations and Management and Active Mode Mobility). Both form groups that meet on a monthly basis to discuss running concerns. Topical clusters or task forces address specific subjects such as public transport, active modes, traffic control, freight transport and railway traffic operations and management. Tenure-track assistant professors meet with full professors on a monthly basis to discuss their (career) development.

T&P stimulates researchers to work in different core application fields. Table 2 shows which researchers are main contributors to which core application fields.
The organisational model as described above was carefully chosen to develop a largely new T&P group during the assessment period. The model aimed at creating a research and education culture of excellence, relevance, teamwork and inspiration. In the

Table 1: Research staff 2011-2016 in the Transport & Planning programme

	2011		2012		2013		2014		2015		2016	
Transport & Planning	**#**	**FTE**	**#**	**FTE**	**#**	**FTE**	**#**	**FTE**	**#**	**FTE**	**#**	**FTE**
Scientific staff (1)	30	8,9	34	10,1	34	10,3	36	9,4	32	9,2	32	9,6
Researchers (2)	14	6,2	17	7,2	13	6,4	15	7,7	14	5,4	17	7,3
PhD candidates (3)	34	19,0	38	21,5	37	21,3	43	21,7	49	24,1	62	34,7
Total Research staff	78	34,1	89	38,8	84	38,1	94	38,9	95	38,8	111	51,6
Support staff	1	0,3	0	0,0	0	0,0	1	0,7	2	1,0	3	1,5
Total staff	79	34,4	89	38,8	84	38,1	95	39,6	97	39,7	114	53,0

(1) comparable with WOPI category HGL (full professor), UHD (associate professor), UD (assistant professor), tenured and non-tenured
(2) includes post-docs and temporary 'onderzoekers'
(3) includes all PhD categories

Table 2: Contributors to the core application fields.

	m/f	H-index (Scopus November 2017)	Network Traffic Operations & Management	Reliable Multimodal Transport Systems	Cooperative and Automated Driving	Active Mode Mobility
Bart van Arem	m	17		●	●	
Arjan van Binsbergen	m	2		●		
Oded Cats	m	10		●		●
Winnie Daamen	f	16	●			●
Haneen Farah	m	10			●	●
Rob Goverde	m	14		●		
Marjan Hagenzieker	f	10	●		●	●
Andreas Hegyi	m	16	●			
Goncalo Homem de Almeida Correia	m	9		●	●	
Riender Happee	m	16			●	
Serge Hoogendoorn	m	32	●	●	●	●
Milan Janic	m	14		●		
Victor Knoop	m	12	●		●	●
Hans van Lint	m	21	●			
Dimitris Milakis	m	5		●	●	
Rob van Nes	m	9		●		
Niels van Oort	m	7		●		
Adam Pel	m	8	●	●		
Erik de Romph	m	3		●		
Henk Taale	m	5	●			
Maaike Snelder	f	4		●	●	
Jaap Vleugel	m	3		●		
Meng Wang	m	7	●		●	
Bart Wiegmans	m	9		●		
Rob Zuidwijk	m	11		●		

future, T&P will reconsider its organisational model in order to further develop its research position by providing more autonomy and responsibility to staff members whilst reducing the managerial burden at senior staff. We aim to further develop internal collaboration, information exchange and scientific debate along 'clusters, task forces and labs' based on core application areas (including current as well as new areas).

1.2.3 FUNDING

Table 3 summarises the funding status of the T&P programme. Over the assessment period 2011-2016, funding increased from 4,3 M€ to 5,4 M€. An increase in the number of MSc students, and specific allocations to relieve educational work load and to support railway research led to additional direct funding via the internal TU Delft financial system. Funding from research grants increased strongly from 0,3M€ to 1,0M€, in particular because of the acquisition of NWO project funds. Contract research for national and international funding organisation, including H2020 (ERC) remained stable at 1,6M€. With the acquisition of the H2020 projects MyTrac (700k€) and SAFE10T (100k€) we expect that this will increase in the coming years. Although 2014 and 2015 show a small negative result due financial corrections within projects by the introduction of a new financial system at TU Delft, the T&P programme is financially in good shape.
T&P aims for a 50-50 ratio between research grants and contract research, since contract research is

Table 3: Overview of the funding and expenditures of the Transport & Planning programme.

Transport & Planning	2011		2012		2013		2014		2015		2016	
Funding:												
Direct funding (1)	2.134	50%	2.080	45%	2.272	44%	2.355	45%	2.360	44%	2.585	48%
Research grants (2)	337	8%	714	15%	789	15%	921	17%	892	17%	1.036	19%
Contract research (3)	1.557	36%	1.581	34%	1.979	38%	1.730	33%	1.679	31%	1.594	29%
Other (4)	245	6%	262	6%	166	3%	271	5%	444	8%	197	4%
Total funding	4.273	100%	4.637	100%	5.206	100%	5.277	100%	5.374	100%	5.412	100%
Expenditure:												
Personnel costs	3.338	81%	3.512	77%	3.860	78%	4.497	83%	4.353	80%	4.690	87%
Other costs	761	19%	1.037	23%	1.061	22%	892	17%	1.088	20%	684	13%
Total Expenditure	4.099	100%	4.549	100%	4.921	100%	5.388	100%	5.441	100%	5.375	100%

Note 1: Direct funding (basic funding / lump-sum budget)
Note 2: Research grants obtained in national scientific competition (e.g. grants from NWO and the Royal Academy)
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

usually well-funded while research grants from NWO are scientifically prestigious but require matching funds. Research grants from the ERC offer better financial conditions. With the appointment of several new tenure-track assistant professors we expect that the contribution of research grants (ERC as a priority) and contract research will grow.

In our project portfolio, we observe a shift from single-party research proposals to consortium proposals, requiring collaboration with and in-kind or in-cash contributions by private as well as public partners. T&P was successful in the acquisition of research funding both as partner and as leader of such consortia. For the future, T&P will continue to capitalise on this funding strategy in collaboration with public and private partners, and increasingly in typical 'smart city, smart regions' research programmes of funding sources such as AMS, NWO-SURF and H2020.

1.3 Scientific quality

During the assessment period, T&P has considerably increased its scientific output and strengthened its research portfolio. In this paragraph, we discuss the main results for each of the above-mentioned themes, followed by the development of our lab facilities. We also provide a summary table of the scientific output and a summary of the awards and personal grants obtained.

1.3.1 RESEARCH THEMES AND MAIN RESULTS

Theme A: Coordinated and Cooperative Network Traffic Operations and Management

For effective traffic management on our busy roads, present-day knowledge is insufficient. Solid theory and accurate models are required to describe and predict network-wide traffic conditions, and to assess the impact of traffic control and management. During the assessment period, we have made ground-breaking contributions in the fields of vehicular data collection using innovative experimental and empirical methods, theory building and macroscopic and microscopic model development. Based on these insights, a firm theoretical basis for the dynamic management of traffic flows under a variety of recurrent (daily congestion) and non-recurrent circumstances (incidents, calamities) has been established, leading to both scientific contributions and large-scale field applications. These contributions have led to numerous scientific publications in top-ranked journals.

The modelling efforts in this theme have focussed on the development of models that are able to

The data that will get you from A to B

Hans van Lint

Going from A to B by car in the Netherlands does not always turn out to be as smooth a journey as we might wish. In spite of extensive data on driver behaviour and traffic intensity, bottlenecks continue to occur in a number of problem areas. The Delft Integrated Traffic & Travel Laboratory (DiTTLab) is modelling traffic flow to flag up potential snags. To prof. Hans van Lint the DiTTLab is a like playground. “We’re playing with data layers. Layered data modelling allows us to come up with answers to ‘what if’ questions’ that we couldn’t have found otherwise.”

www.tudelft.nl/en/ceg/research/stories-of-science/the-data-that-will-get-you-from-a-to-b/

reproduce the key flow phenomena, while keeping an eye on the model and computational complexity. Multiclass generalisation of traffic flow theory has led to many new scientific contributions, as well as to some key engineering products from analysis, state estimation and data fusion, prediction, and control. The novel Lagrangian formulation of the multiclass model Fastlane has enabled more accurate predictions, and opened up new avenues for advanced multi-class state estimation, data fusion, and real-time prediction. Next to these multiclass generalisations, network aggregate modelling has led to novel traffic flow theory concepts describing the relation between average network load, spatial density variation, and average network production, and network outflow. Theories on the dynamic properties of the networks (how do congestion patterns shift) have been developed; our work on dynamic OD estimation has continued as well. Furthermore, our investigations have revealed the importance of including uncertainty in the modelling of network traffic operations, also for determining the network impact of interventions. To enable large-scale simulation and control, we have initiated research on multi-scale approaches during the assessment period, focussing on the issues related to the coupling of traffic representations and behavioural theories at different scales.

As traffic flow theory is largely based on inductive methods in which data collection and analyses form a crucial part, the T&P field laboratory facilities and its constituent advanced data collection techniques have been put to use extensively and effectively. Among the data collected are the innovative airborne video-based driver behaviour data collection, and the data collection on travel behaviour under normal and exceptional conditions using a sophisticated interactive virtual lab (serious gaming) and a driver simulator. Moreover, the impact on driver route choice behaviour has been studied using GPS tracks. We established the Urban Mobility Lab in the Amsterdam Institute of Advanced Metropolitan Solutions, as a logical continuation of the Regiolab project. The creation of this new data and modelling lab has opened up new research avenues to develop empirically underpinned theories. At the same time, advanced techniques for the real-time multi-class estimation and prediction of the current traffic state given multiple data sources have been developed. In relating state estimation accuracy and reliability to controller effectiveness, we have gained the first ever insights into the value of data quality.

Cooperative and coordinated network management has focussed on the application of traffic flow theory to increase the utilisation of available infrastructure, aimed at bringing the traditionally isolated, road-based control approaches to the next level, implying integration at the network level, considering different user classes, and integration of in-car information and cooperative control approaches in the overall traffic management framework. The conducted research has provided new theory for the real-time cooperative control of vehicle platoons, shock wave removal using dynamic speed limits, coordinated and network-wide traffic management, robust evacuation management, and even crowd management. Our research on multi-class control theory has focussed on advancing model-predictive control applications, making them suitable for real-time large-scale (network-wide) applications. We focussed in particular on linear representations of queuing systems and first-order network models allowing the efficient use of advanced solvers, and generalising these models to capture the key flow phenomena (such as the capacity drop and spill-back) without compromising their favourable analytical and computational properties. The application-oriented investigations for traffic control have also led to new analysis methods to identify under which conditions traffic management measures are meaningful. Further development of control heuristics has resulted in the development of a monitoring and control framework for Integrated Network Management in Amsterdam on behalf of the national road authority RWS, which has led to a large field trial in 2014.

As a final subtheme, we have considered network modelling and management of the traffic and transportation system in case of disasters such as flooding in the course of the NWO-VICI project Liberate. The model EVAQ was developed, and integrated in a robust bi-level optimisation framework. Using this framework, new insights were gained in the perspectives of optimising evacuation instructions given the many uncertainties with respect to behavioural responses, as well as the disaster characteristics and dynamics. Model development was achieved by including recent results from survival psychology and by innovative data collection using advanced driving simulator experiments and serious gaming techniques.

Transport Transformations

Oded Cats

Within the realm of transport planning and operations, the research interests of Oded Cats are very broad. "I like the whole spectrum of subjects, from being involved in evaluating the free public transport policy in Estonia to assessing the capacity and robustness of the new North-South line in Amsterdam. I also like using detailed models about how to synchronise transfers, or what information to provide travellers with in case of disruption." The common ground here is in the underlying methodologies, that are based on dynamic stochastic models. "The idea is that we are able to mimic in our models how systems evolve over time. Traffic dynamics and travellers' route decisions interact.''

www.tudelft.nl/en/ceg/research/stories-of-science/transport-transformations/

Key publications:

- Van Hinsbergen, C.P.I.J., Hegyi, A., Van Lint, J.W.C., Van Zuylen, H.J. Bayesian neural networks for the prediction of stochastic travel times in urban networks (2011) IET Intelligent Transport Systems, 5 (4), pp. 259-265.
- Ossen, S., Hoogendoorn, S.P. Heterogeneity in car-following behavior: Theory and empirics (2011) Transportation Research Part C: Emerging Technologies, 19 (2), pp. 182-195.
- Knoop, V.L., Snelder, M., van Zuylen, H.J., Hoogendoorn, S.P. Link-level vulnerability indicators for real-world networks (2012) Transportation Research Part A: Policy and Practice, 46 (5), pp. 843-854.
- Yuan, Y., Van Lint, J.W.C., Wilson, R.E., Van Wageningen-Kessels, F., Hoogendoorn, S.P. Real-time Lagrangian traffic state estimator for freeways (2012) IEEE Transactions on Intelligent Transportation Systems, 13 (1), art. no. 6126042, pp. 59-70.
- Knoop, V.L., Van Lint, H., Hoogendoorn, S.P. Traffic dynamics: Its impact on the Macroscopic Fundamental Diagram (2015) Physica A: Statistical Mechanics and its Applications, 438, art. no. 16247, pp. 236-250. Cited 6 times.

Theme B: Reliable Multimodal Transport Systems
Reliable multimodal transport systems are vital for the economic and societal development of regions from the local up to the national scale. Transport modes are increasingly interconnected, demand patterns are increasingly diverse, and funds for investment, operation and management of transport systems are increasingly scarce. Therefore, new scientific knowledge is urgently needed to understand the future functioning of transport systems. In the assessment period, structural advances were made by extending the scientific staff and expanding the research portfolio to further develop scientific research in order to support the planning and design of reliable multimodal transport. The empirical basis consists of surveys; Automated Vehicle Location, smartcard and GSM data; and traffic measurements for travel-demand modelling and Origin-Destination estimation. Traffic and network data are used for improved network modelling.

In order to support the planning and design of multimodal transport systems, we made important progress in developing strategic transport models that are more realistic by incorporating dynamics in an efficient and realistic way; that are more comprehensive by improving multimodality; and that make use of state-of-the-art travel-demand models. Semi-dynamic modelling of congestion (STAQ) was developed to improve congestion modelling in static models and realistic, flexible and efficient dynamic macroscopic link and node models were developed as part of dynamic assignment models. Multimodality was improved by developing multimodal dynamic assignment models based on hyper-networks. Furthermore, the models were extended for specific conditions such as events and emergencies, specific purposes such as robustness and resilience of transport systems and applications such as pricing automated vehicles, on-demand transport services and sharing.

Advances in demand modelling were made by using activity-based modelling, multimodal choice models, generalised multiplicative as well additive route choice models and modelling crowding. Research on travel behaviour focused on defining network levels based on characteristics of observed trips in collaboration with the French LVMT, and the analysis of long-distance travelling in Europe with a special focus on railways and environmental impact. The analysis of choice behaviour in multimodal networks was studied, such as the preference for tram versus bus services, and the role of service reliability in route choice.
The research into multimodal network design focused on the network analysis and design for the Dutch Railways and the bus network of the city of Utrecht, and on the analysis of the robustness of multi-level public transport networks. For car-sharing systems in urban regions, we focused on the imbalance problem of vehicle stocks around the different neighbourhoods for systems where clients can take a car and leave it anywhere in the city. We developed new models to optimise the pricing of this service toward a more balanced demand and to assess the impacts of mixing one-way and round-trip car-sharing in the same service provider.

An innovative railway timetabling framework was developed that combines innovative timetable construction as well as evaluation methods to automatically generate robust conflict-free and energy-efficient timetables for large railway networks. A closed-loop railway real-time traffic management architecture was developed which integrates automated traffic monitoring, prediction,

A self-driving car to transport wheelchair-bound children?

Niels van Oort & Arthur Scheltes

How feasible would it be to use driverless vehicles to transport children with multiple disabilities from day care centre Omega in IJburg (Amsterdam) to their new home some 400 metres away? That is what a group of parents asked TU Delft. They would like flexible and small-scale transport to cover the short stretch of road so their children can get from one place to the other more quickly and whenever they want. Researcher Niels van Oort and his colleagues were intrigued and set about investigating.

www.tudelft.nl/en/ceg/research/stories-of-science/a-self-driving-car-to-transport-wheelchair-bound-children/

conflict detection and resolution, route setting and energy-efficient driver advice. Moreover, data-driven railway traffic models were developed to analyse delay causes and predict train journey times and conflicts over large networks using real-world track occupation data.

For urban public transport, specific attention was given to reliability, resulting in new insights into for instance holding and transfer reliability. We also demonstrated the value of a new passenger-oriented metric concerning service reliability. We developed new methods to incorporate reliability from a passenger perspective, comfort and the perceived rail bonus in transport models and societal cost benefit analyses. A new approach was developed to assess the costs of multimodal network robustness and the expected benefits of measures. Smart card data were applied to develop a new ridership prediction model.

Research on freight transport in main-ports focused on energy efficiency and emission, cost, competition and information in freight transportation. In addition, it focused on the competitive position of intermodal freight transport versus single-mode road transport and the value of information in container transport chains. The 'relationship of deep-sea ports with inland ports' is a new research area, already resulting in very relevant findings. The well-established research on 'airport operational, economic, and environmental performances' develops innovative modelling and evaluation methods of possible effects of innovative technological and operational short-, medium-, and long-term solutions.

Key publications:

- Cats, O., Jenelius, E., Planning for the unexpected: The value of reserve capacity for public transport network robustness. (2015) Transportation Research Part A: Policy and Practice, 81, pp. 47-61.
- Cavadas, J., de Almeida Correia, G.H., Gouveia, J., A MIP model for locating slow-charging stations for electric vehicles in urban areas accounting for driver tours (2015) Transportation Research Part E: Logistics and Transportation Review, 75, pp. 188-201.
- Goverde, R.M.P. & L. Meng , Advanced monitoring and management information of railway operations Journal of Rail Transport Planning and Management, Vol 1, Issue 2, December 2011, pp 69-79
- Smits, E.S., M.C.J. Bliemer, A.J. Pel, B. van Arem, A family of macroscopic node models. (2015) Transportation Research Part B, 74:20-39
- Wiegmans, B., Witte, P., Spit, T., "Characteristics of European inland ports: A statistical analysis of inland waterway port development in Dutch municipalities", (2015) Transportation Research Part A: Policy and Practice, Volume 78, August 01, 2015, Pp. 566-577

Theme C: Cooperative and automated driving

Research in cooperative and automated driving has recently been gaining enormous attention in the academic, industrial and public sectors. Due to previous investments in this field, T&P has been able to match this growing attention with a strong research portfolio. At T&P, this research theme consists of (informative) cooperative driving, controller design, human factors and traffic safety, mobility services and impact assessment.

The field of cooperative driving focuses on the use of communication between vehicles and vehicles and infrastructure to support drivers by means of information or advice. We developed new rule-based methods for tactical driving advice regarding speed, headway and lane use and developed open-source traffic-flow simulation software MOTUS to evaluate the effectiveness of the advice. We extended previous work on dynamic speed limits into dynamic in-car speed limits, comprising improved traffic state and congestion wave detection using fusion of in-car and roadside data. We evaluated the operation and impacts of a field trial of in-car traffic management in Amsterdam, in which personalised route advice were given in real-time, showing that drivers have a very strong tendency to stick to their habitual route. However, in strongly deviant traffic conditions, 70% is willing to comply with personalised route advice. User compliance regarding advice toward system rather than user optimum was also studied in real-world conditions by considering indifference bands and in an interactive multi-user route choice simulator using incentives.

In the field of controller design of automated driving, a model-predictive control-based framework was developed to design vehicle longitudinal control systems, and used to design full speed range Adaptive Cruise Control (ACC) and Cooperative ACC (CACC) systems. String stability criteria of ACC and CACC systems were examined with linear stability theory. Efficient solution algorithms are derived

The bike lane as a laboratory

Serge Hoogendoorn, Yufei Yuan & Winnie Daamen

'Ready? GO!' A white flag drops and two participants in green caps start pedalling their OV bike (bikes obtainable for a small fee from public transport hubs). Another participant cycles towards the other two from the opposite direction. Cameras above the lane record everything. What will the cyclists do to avoid contact? Next to the bike lane on the TU Delft campus, researcher Yufei Yuan is taking notes. He is trying to work out how cyclists respond to one another. The data collected will be used to develop a traffic theory for cyclists as this groups behaviour is much more complex than that of fast traffic.

www.tudelft.nl/en/ceg/research/stories-of-science/the-bike-lane-as-a-laboratory/

and implemented in microscopic traffic simulation to test the impacts of ACC and CACC systems on roadway capacity and traffic flow stability. Eco-ACC controller under the eco-driving concept was also designed and tested. A game-theoretical framework was developed to plan optimal path of autonomous and cooperative vehicles, taking into account anticipated changes in the imminent driving environment. Intelligent vehicles were used as actuators for traffic control systems by integrating a link-level variable speed limit (VSL) controller and the vehicle-level ACC controller with V2I communication. The link-level controller estimates and predicts the global traffic state and constructs VSL schemes to resolve stop-and-go waves. Simulation experiments show that the integrated control concept is able to resolve stop-and-go waves. For traffic flow at sags, we showed how model predictive and feedback in-vehicle control can reduce congestion.

Human factors and traffic safety are crucial research topics for automated driving. Theoretical frameworks for situation awareness during prolonged automated driving and authority transitions between automation levels were developed and form the basis of currently ongoing driving simulator studies and field experiments.

T&P research on automated driving as mobility service focuses on self-driving vehicles as public transport or private transportation. We studied and developed a system of small electric vehicles as a feeder system to a train station, hence contributing to a seamless public transport trip, by means of transport system modelling, simulation, optimisation and user characteristics. In our new vehicle lab, we collaborated with the Faculty of 3mE to develop the fully automated WePod vehicle that had its first public automated trip to connect the train station of Ede-Wageningen and the Wageningen University in the Gelderland Province in February 2016.

We started research on the impacts of automated driving in 2015, focusing on the transport and spatial impacts of automated driving and the strategic decision making for public authorities. The research takes an interdisciplinary approach and focuses on scenario development, accessibility modelling, travel and location choice modelling, land-use modelling and impact assessment. We created the first holistic, system-wide theoretical framework (the ripple effect model) to represent implications of automated driving at three stages: first-order (traffic, travel cost, and travel choices), second-order (vehicle ownership and sharing, location choices and land use, and transport infrastructure) and third-order (energy consumption, air pollution, safety, social equity, economy, and public health). On behalf of the Dutch Environmental Planning Agency, we created scenarios about development of automated vehicles and implications on traffic, travel behaviour and transport planning for 2030 and 2050 in the Netherlands.

Key publications:

- De Almeida Correia, G.H. & B. van Arem, The Privately Owned Automated Vehicles Assignment Problem: a model to assess the impacts of private vehicular automation in urban mobility, (2016) Transportation Research Part B: Methodological, 87, 64-88
- Milakis, D., M. Snelder, B. van Arem, B. van Wee, G.H. de Almeida Correia, Scenarios about development and implications of automated vehicles in the Netherlands, Proceedings 95th Transportation Research Board Annual Meeting, (2016), paper 16-0765. Also appeared in European Journal of Transport and Infrastructure Research 2017, 17 (1), 63-85.
- Schakel, W., B. van Arem, Improving traffic flow efficiency by in-car advice on lane, speed and headway, (2014) IEEE Transactions on Intelligent Transportation Systems, 15 (4) pp 1597-1606
- Varotto, S. F., Hoogendoorn, R. G., B. van Arem, & S.P. Hoogendoorn, Empirical longitudinal driving behaviour in case of authority transitions between adaptive cruise control and manual driving. (2015) Transportation Research Record No. 2489, Transportation Research Board, Washington, D.C., 2015, pp. 105–114.
- Wang, M., S.P. Hoogendoorn, W. Daamen, B. van Arem, R. Happee. Game theoretic approach for predictive lane-changing and car-following control, (2015), Transportation Research Part C-Emerging Technologies, 2015, 58, 73-92.

Theme D: Active Mode Mobility

A major challenge in contemporary traffic and transportation theory is to arrive at a comprehensive understanding of pedestrian and cyclist behaviour. With slow traffic modes gaining ground in terms of mode share in many cities, the current lack of empirical insights, behavioural theories, predictive analytical and simulation models, and tools to support

planning, design, management and control is posing a major societal problem. This theme deals with the traffic and transportation theory of pedestrians and cyclists, and as such forms a key element of the (urban) transport system.

In particular the topic of pedestrian flow theory and management has revealed many challenging issues in data collection, modelling, simulation, control and facility design, that have been the centrepiece of the research within the theme. T&P has taken a world leading position in this field, as is evidenced by the roles the researchers in this team play (organisation of topical conferences, leadership of academic committees, invitations for keynote addresses, etc.).

Our ground-breaking work on pedestrian flow theory and modelling is based on innovative data collected via controlled walker experiments and via sophisticated empirical data collection efforts in the field for many, archetypical situations during events and in stations using newly developed video-based data collection techniques including drones and Wifi/BT sensors. These data have been used to test the behavioural theories that underlie the microscopic and macroscopic models that have been developed in the past years. Our microscopic simulation tool NOMAD has been calibrated and validated using these innovative data, applying newly developed calibration techniques. Next to pedestrian flow operations, travel-choice behaviour theory has been an important research theme: to this end, we aimed at understanding choice behaviour and its determinant factors (including herding) via sophisticated stated preference and virtual reality experiments. In doing so, considerable contributions in terms of theory and modelling have been made.

Based on the aforementioned microscopic theory, a unique two-dimensional multi-class macroscopic modelling approach has been put forward that inherent the main properties of the underlying microscopic model. This model is the first macroscopic model that reproduces self-organisation phenomena observed in pedestrian flow, including the (spontaneous) phase transitions from laminar to turbulent flow. Also, heterogeneity appears to have a considerable influence on pedestrian flows. Newly developed model representations using Lagrangian coordinates result in accurate numerical solvers and provide new alleyways for connecting microscopic and macroscopic models (multi-scale modelling). Furthermore, work on optimisation of evacuation schemes and crowd management has been conducted using these new macroscopic models.

Using our new insights into the characteristics of pedestrian flows and crowds, crowd management theory and methods has been developed. Next to a general framework for crowd management, a mathematical optimisation framework was developed using the developed macroscopic model. This framework will form the basis for a real-time crowd management system that will be developed in the coming years. First steps towards the practical implementation of such a system have been made during SAIL 2015 (and followed up in multiple city events, including Europride, Kingsday, and Mysteryland), where a crowd monitoring dashboard was designed, developed and implemented, combining multiple data sources (Wifi, counting cameras, GPS and social-media data) to achieve the best estimate of the current system state using advanced data fusion techniques. Future work involves hybrid (data-driven / model-based) prediction of active mode traffic movements.

Since 2015, the ERC Advanced Grant project ALLEGRO furthers the active mode research at T&P by also investigating traffic and travel behaviour of cyclist in cities, collecting data to unravel this behaviour as well as to effective manage active mode traffic flows. In the first year, state-of-the-art analyses of a large-scale GPS data collection experiment have already revealed new insights into cyclist route choice. Several other data collection activities have been performed as well (including a interaction experiment, and a wayfinding experiment).

Key publications:

- Duives, D.C., Daamen, W., Hoogendoorn, S.P. State-of-the-art crowd motion simulation models (2014) Transportation Research Part C: Emerging Technologies, 37, pp. 193-209.
- Hoogendoorn, S.P., Van Wageningen-Kessels, F.L.M., Daamen, W., Duives, D.C. Continuum modelling of pedestrian flows: From microscopic principles to self-organised macroscopic phenomena (2014) Physica A: Statistical Mechanics and its Applications, 416, pp. 684-694.
- Daamen, W., Hoogendoorn, S.P. Emergency Door Capacity: Influence of Door Width, Population Composition and Stress Level (2012) Fire Technology, 48 (1), pp. 55-71.
- Daamen, W., Hoogendoorn, S. Calibration of pedestrian simulation model for emergency doors by pedestrian type (2012) Transportation Research Record, (2316), pp. 69-75.
- Duives, D.C., Daamen, W., Hoogendoorn, S.P. Quantification of the level of crowdedness for pedestrian movements (2015) Physica A: Statistical Mechanics and its Applications, 427, pp. 162-180.

1.3.2 LAB FACILITIES

The T&P empirical traffic laboratory aims to collect data that are of use to researchers to derive new insights, theories and models on travel and traffic behaviour. The laboratory has a variety of data-collection techniques at its disposal, ranging from video cameras via radars and in-house developed Wifi sensor technology to GPS trackers. The laboratory provides the opportunities to collect microscopic traffic data using cameras mounted on helicopters, UAVs, balloons, and McSavi (in-house developed multi-camera stand-alone video installation), to perform sophisticated and interactive surveys (via Internet, using tablets), to set up large-scale experiments e.g. to investigate pedestrian flows, and to use GPS and infrared sensors to respectively track and count travellers. Social-media data is harvested to enrich these data; apps have been developed to track people (e.g. during events) and collect data via short surveys. Specific software tools have been developed to stabilise video images (e.g. collected with a helicopter or with our in-house developed trackers) and to automatically detect and track traffic participants. The results are highly accurate trajectories of vehicles and pedestrians, while plans exist to extend the tooling for cyclists.

A Toyota Prius has been acquired and equipped with radars, cameras, a telematics platform and GPS to act as instrumented vehicle, for naturalistic, supported and automated driving. Our fleet of vehicles has recently been extended with 2 WEpods (courtesy Province of Gelderland) and a Renault Twizy, all equipped to allow research on automated driving. For the equipment of the vehicles, the traffic laboratory closely collaborates with the Faculty of 3mE at TU Delft.
The T&P driving simulator provides a unique, safe, and cost-efficient method for collecting empirical data on driving behaviour, yielding insights into the impact of human factors. It is used for studying and testing drivers' reactions and behaviours in existing and new road infrastructure designs, in risky situations, and as well for testing the impact of new technologies and in-vehicle driving assistance systems on driving behaviour. The T&P driving simulator was used to study the empirical longitudinal driving behaviour in case of authority transitions between adaptive cruise control and manual driving, to study how city visitors find their way out during evacuation in case of disasters, and to establish the impact of road complexity on driver behaviour. In order to structurally advance our driving simulator research and to connect it to other research fields, we purchased two fixed-base driving simulators from GreenDino of the type Classic LT with an open driving simulator architecture based on the software Unity 3D. Each driving simulator has three 42-inch LED TV screens with a resolution of 4K UHD, together providing a 210° field of view. The availability of two driving simulators will allow us to connect them to each other in order to have two human drivers interacting in the same driving scenario, providing an improved research environment.

The Delft integrated Traffic and Travel Laboratory (DiTTLab) was started in 2013 as follow-up of Regiolab-Delft, in which a historical database is maintained that contains all the highway loop detector data from 2006 until today. Regiolab-Delft supports the discovery of new patterns and phenomena, the development of new theories, models and predictions, as well as the verification and validation by new data. Regiolab-Delft played a central role in PhD projects on (1) Fusing Heterogeneous Traffic Data: Parsimonious Approaches using Data-Data Consistency, (2) Lagrangian Multi-Class Traffic State Estimation and (3) Vehicle-class Specific Route-guidance of Freeway Traffic by Model-predictive Control. Regiolab-Delft was extensively used in the NEARCTIS Network of Excellence project (EU FP7), and various other research projects sponsored by e.g. STW and Rijkswaterstaat. DiTTlab extends the Regiolab database to also contain data from provincial roads and the four largest cities, and data related to weather, activities, maps, and many more relevant factors. We aim to couple these data with (traffic simulation) models and advanced methods and algorithms for state and parameter estimation, demand estimation. We are developing these methods and models within the OpenTrafficSim (OTS) environment, an open-source multi-scale, multi modal simulation platform in which T&P collaborates with the Systems and Simulation group at the

Faculty of TPM. DiTTLAB is set up as a collaboration environment in which today many partners (CGI, NDW, Grontmij, NISSAN, RWS, Bureau Bereikbaar, DiTCM) collaborate in a growing number of research projects that centre on both data and simulation.

1.3.3 GRANTS/AWARDS

Personal grants

- Serge Hoogendoorn (2009 – 2015): NWO Vici – Travel Behaviour and Traffic Operations in case of Exceptional Events (1.250k€)
- Winnie Daamen (2013): NWO Aspasia – Crowd Management (200k€)
- Victor Knoop (2013 - 2016): NWO Veni – Integrated Driving Behaviour Theory and Models: there is plenty of Room in the other Lane (250k€)
- Serge Hoogendoorn (2015 – 2020): ERC Advanced Grant - unrAvelLing sLow modE travelinG and tRaffic – with innOvative data to a new transportation and traffic theory for pedestrians and bicycles (ALLEGRO) (2.500k€ + 450k€)

Awards and honours

- Man, W., J Bie, B van Arem (2010), User needs in Green ITS: the results of a questionnaire survey on Dutch and Japanese drivers, - 17th ITS World Congress, 2010, Busan, Korea. Best conference paper award
- Schakel, W., V. Knoop & B. van Arem (2012), Integrated lane change model with relaxation and synchronization, Transportation Research Record 2316, pp 47-57, 2012 Greenshields prize TRB Traffic Flow Theory Committee
- B Goñi Ros, VL Knoop, B van Arem, SP Hoogendoorn (2012), Reducing congestion at uphill freeway sections by means of a Gradient Compensation System, IEEE Intelligent Vehicles Symposium 2012, Nominated Best student paper
- Hegyi, A., B.D. Netten, M. Wang, W. Schakel, T. Schreiter, Y. Yuan, B. van Arem, T. Alkim (2013) cooperative system based variable speed limit control algorithm against jam waves-an extension of the SPECIALIST algorithm, Proceedings 16th International IEEE Conference on Intelligent Transportation Systems, Runner-up Best Paper Award
- Netten, B, Hegyi, A, Wang, M, Schakel, WJ, Yuan, Y, Schreiter, T, Arem, B van, Leeuwen, C. van & Alkim, T (2013). Improving moving jam detection performance with V2I communication. 20th ITS world congress, 2013, Japan. Best conference paper award.
- Wang, M. (2013), Chinese Government Award for Outstanding Students Abroad, 2013.
- Calvert, S., Snelder, M., Bakri, T., Heijligers, B. and Knoop, V.L. (2015) Real-Time Travel Time Prediction Framework for Departure Time and Route Advice, Transportation Research Record 2490, pp 56-64, 2015 Greenshields prize TRB Traffic Flow Theory Committee.
- Wang Y., Correia G., de Romph E. (2015) National and Regional Road Network Optimisation for Senegal Using Mobile Phone Data. Best paper in transportation on the Orange Data for Development challenge. NetMob: The main conference on the scientific analysis of mobile phone datasets, 7-10 April 2015, MIT Media Lab, Boston, USA
- Wang, M. , 2nd Prize Best PhD Dissertation Award of IEEE Intelligent Transportation Systems Society, 2015.
- Serge Hoogendoorn was appointed honorary professor at the South East University in Nanjing in 2014; honorary professor at Swinburne University in Melbourne in 2014.
- Serge Hoogendoorn was invited to provide the TU Delft Dies Natalis lecture in 2011.
- Serge Hoogendoorn was appointed Distinguished Professor Smart Urban Mobility in 2016.

1.3.4 RESEARCH OUTPUT

Table 4 summarises the scientific output. The yearly number of journal papers has increased from 26 (average 2005-2010) to 54 (2011-2016), reaching a peak of 97 in 2016. Many of these papers were published in highly ranked journals such the Transportation Research series and IEEE Transactions on Intelligent Transport Systems.

Table 4 also shows a remarkable increase in the number of publications aimed at the general public and other research output as a result of increasing dissemination efforts to practitioners and via media as well as editorships.

During the assessment period, 26 PhD theses were produced, amounting to 4.3 theses per year. These theses were predominantly (21) produced as part of PhD projects started in 2008-2012, whilst 5 theses originate from PhD projects started before 2008. Based on the increased number of PhD candidates appointed in 2014-2016 (Table D3a), a growth of the number of PhD theses per year is expected in the future.

Table 4: Main categories of scientific output for the Transport & Planning programme.

Transport & Planning	2011	2012	2013	2014	2015	2016
Refereed articles	31	36	34	52	71	97
Non-refereed articles (1)	1	0	1	0	3	0
Books	1	1	1	0	1	2
Book chapters	3	7	3	8	11	5
PhD theses	4	1	7	4	2	8
Conference papers	82	95	79	91	95	59
Professional publications (2)	33	14	36	42	35	21
Other research output (3)	17	40	121	124	151	159
Total publications	172	194	282	321	369	351

Note 1: Articles in journals that are non-refereed, yet deemed important for the field
Note 2: Publications aimed at professionals in the public and private sector (professionele publicaties), including patents and annotations (e.g. law)
Note 3: Other types of research output, such as patents, book reviews, editorships of books, editorships of journals, inaugural lectures, abstracts, designs / prototypes, appearances on radio or television, "populariserende artikelen" and other research output (internal reports, lectures)

The visibility in scientific networks was further increased by hosting prestigious international scientific conferences such as the 2013 International Symposium of Traffic and Transport Theory, the 2013 IEEE Intelligent Transport Systems Conference, Pedestrian and Evacuation Dynamics 2014, the European Working Group on Transportation EWGT (2015), Traffic and Granular Flow 2015 and the 2016 Triennial Symposium on Transportation Analysis (TRISTAN). Many staff members are active as Associate Editor in prestigious journals such as the Transportation Research Series and IEEE Transactions on ITS.

1.3.5 PHD CANDIDATES

The majority of the scientific research is conducted in the form of PhD research projects. Table 1 already showed that the number of PhD candidates increased from 34 to 62 during the assessment period. In general, each PhD candidate has a daily supervisor (assistant/associate professor) and one or two full professors as promotor. A go/no-go decision based on a research plan and presentation for a wider committee was introduced at T&P in 2009 and later formalised by the Graduate School of the Faculty of Civil Engineering & Geosciences (CEG). PhD candidates are encouraged to present and publish their work at conferences and journals during the project and a typical PhD thesis is based on 3-4 journal papers. The PhD community currently constitutes a vibrant and coherent group, for instance organising academic debate in so-called SPARKS meetings. The increase in the number of appointments of PhD candidates offers opportunities for newly appointed staff members to supervise PhD candidates.

The standard duration of a PhD research project in the Netherlands is four years. In cases where PhD candidates substantially contribute to other tasks such organisation, education, contract research or in cases of maternity leave or longer periods of illness, the contract is extended. After that, candidates need to finish their thesis in their own time. In some cases a next employer allows the candidate to work on the thesis during working hours as well.

Table 5 summarises the graduation status of the 33 PhD candidates appointed in 2008-2012 (excluding 12 part-time (<0,6 fte) PhD candidates). Of the 33 candidates, 21 graduated and 6 left (mostly in their 1st year either after a no-go or for personal reasons). Table 5 shows that of the 27 candidates that continued, 11 (41%) graduated within 5 years. After 5 years, the candidates are typically employed elsewhere and need to find sufficient time to finish their thesis. The 6 candidates in Table 5 that did not graduate yet have completed the research and are writing their theses in their own time. The programme maintains contact with all of them and with their employers in order to free up sufficient time to finish the thesis.

Table 5: PhD candidates in the Transport & Planning programme

Starting year	Female	Male	Total	Grad.	Grad. <= 4 yr		Grad. <= 5 yr		Grad. <= 6 yr		Grad. <= 7 yr		Not yet finished		Discontinued	
2008	4	2	6	5	1	17%	4	67%	4	67%	5	83%	1	17%	0	0%
2009	3	6	9	7	1	11%	3	33%	7	78%	7	78%	1	11%	1	11%
2010	2	5	7	3	0	0%	1	14%	2	29%	3	43%	3	43%	1	14%
2011	2	2	4	1	0	0%	1	25%	1	25%	1	25%	1	25%	2	50%
2012	3	4	7	2	0	0%	2	29%	2	29%	2	29%	3	43%	2	29%
	14	19	33	18	2	6%	11	33%	16	48%	18	55%	9	27%	6	18%

Note: This table includes Standard PhD candidates (with employee status) and Contract PhD candidates (without employee status, receiving external funding) conducting research with the primary aim/obligation of graduating, based on a 0,8-1,0 FTE contract. Please note that the data in the dark cells is incomplete. There are still PhD candidates active from those starting years that are able to graduate within the timeframe of the given years. Reference date: 1 januari 2017

Our PhD candidates found employment in research (65%), industry (23%) and government (8%). One PhD candidate retired directly after obtaining his PhD. T&P aims to increase the percentage of PhD candidates graduating within 5 years. In collaboration with the CEG-Graduate School the formal organisation, monitoring and educational programme have been improved. We have improved our recruitment procedures by extending the interview panel with researchers not directly involved in the research. Finally, we are using stricter criteria for past performance on research, relevant expertise and language skills.

1.4 Societal relevance

It is beyond doubt that the planning and operation of safe, sustainable and efficient transport systems is of extreme societal and economic importance. The growing and diversifying nature of transport flows, scarcity of space and resources for transport infrastructure as well as strong technological development such as connectivity, automation, electrification and greening of transport, pose considerable challenges to the planning and operation of transport systems. T&P research is typically conducted in Living Lab settings, naturally creating collaboration with public and private organisations. At a national level, such Living Lab settings are in the AMS institute of Advanced Metropolitan Solutions, the Dutch Integrated Test Site for Cooperative Mobility and the Metropolitan region Rotterdam The Hague (MRDH), whilst numerous collaborations have also been established abroad.

The close involvement of societal stakeholders is also apparent from the fact that a substantial number of employees have part-time positions at TU Delft funded by their employer, varying from the level of full professor (Goudappel Coffeng, Port of Rotterdam), assistant professor (Goudappel Coffeng, TNO) and PhD researcher (Goudappel Coffeng, NS, Innoz, TNO, SWOV, SWECO, Witteveen & Bos). Finally, MSc final thesis projects are conducted at societal stakeholders on research subjects at the frontier of the scientific state of the art.
Our scientific results are presented to and discussed with societal stakeholders regularly in the form of invited presentations and post-graduate courses, workshops and conferences. T&P annually organises the national PLATOS conference on transport modelling, the international course on planning public transport systems (PPTS) and the Delft Road Safety Course. Annually, T&P hosts several international summer schools on Sustainable Mobility in collaboration with Northeastern University Boston. The next sections describe our activities focussing on societal impact for the different themes.

Theme A: Coordinated and Cooperative Network Traffic Operations and Management
The efficient use of available infrastructure to increase throughput, and network robustness, while safeguarding safety and reducing pollution and noise levels has been a key objective for many public stakeholders at the national and regional levels. It has been shown that traffic management can contribute to this efficient use, but also that it has severe limitations due to its traditional isolated nature. Since the late nineties, applied research has focussed on the more effective deployment of traffic management and control by innovative traffic management approaches, including the coordination of control measures at the network level.

While many of the previously discussed theories have led to new theoretical insights and robust optimisation approaches, researchers in this theme have not shied away from valorisation of their results: T&P has been the lead developer of a regional traffic management and control system piloted in Amsterdam (the PPA project), which is now being deployed in various locations in The Netherlands (POC Utrecht, AFM Rotterdam), while also having developed a prize-winning control approach for shockwave removal with dynamic speed limits implemented on the A12 highway. Besides being of great practical use, these field applications have in turn lead to new theoretical insights for effective and robust control of traffic.
Next to these direct field applications, researchers and professionals use the methods and techniques for real-time state estimation, data fusion, model calibration and validation, and image processing broadly. This also holds for the developed models and simulation tools, which have been applied for real-time prediction of travel times.

Theme B: Reliable Multimodal Transport Systems
Multimodal transport systems are key to the functioning of increasingly urbanising areas. Demographic, economic and technological developments are leading to increased dynamics both in terms of transport-related problems as well as solutions. In our research on transport modelling, we collaborate closely with the Dutch Ministry, local governments (cities) and commercial companies. We conducted an explorative study into the modelling of automated driving in the Dutch national modelling system as well several audits and second opinions.

In our NWO-funded projects, practitioners are involved in the articulation of research needs as well as in the assessment of the societal relevance of the project results. Our research on public and collective transport is conducted in close collaboration with authorities (Amsterdam, Den Haag, Rotterdam, Utrecht), operators (NS, GVB, HTM, RET), and ProRail. Results on railway timetabling and traffic management were disseminated to the industry at four seminars in Sweden, Italy, UK and the Netherlands, and on InnoTrans in Germany.

Shared mobility is growing significantly with much impact on the liveability of the cities. Examples of research insights that were directly applied into practice are railway timetable assessment, assessment of new tram lines, and our models based on smart card data for the main urban public transport operators (Amsterdam, Rotterdam, The Hague). For the Dutch Parliament we analysed the prospects of the European Rail Traffic Management System (ERTMS) in the Netherlands, which led to the decision by the Dutch government to migrate the Dutch railway network to ERTMS. We were involved in the advisory group to the Dutch Parliamentary Committee that conducted the parliamentary inquiry into the Fyra (the high-speed rail connection that was planned between Amsterdam and Brussels) and invited as experts in several hearings of the Dutch Parliament. We reviewed several projects on ERTMS and railway infrastructure design of the Dutch Ministry of Infrastructure and the Environment, and they are defining guidelines on cost benefit analyses based on our research insights.
Our research on main-ports aims to get better quantitative understanding in (innovative) transport processes and contributes to the development, assessment and implementation of new approaches to increase overall social-economic benefits whilst reducing negative externalities. Research is often conducted in collaboration with industry, stakeholders and programmes (TKI Logistics, Port of Rotterdam/SmartPort, EU-SESAR and U.S.-NexGen).

Theme C: Cooperative and automated driving
Cooperative and automated driving is stirring great interest amongst public and private stakeholders because of its game-changing potential in transport. T&P co-founded the Dutch Automated Vehicle Initiative (DAVI). The 2013 DAVI demonstration of a cooperative three-vehicle platoon splitting and merging manoeuvre on the A10 motorway in mixed traffic laid the foundation for the Dutch policy to support field tests of cooperative and automated driving. The T&P results on cooperative driving has led to applications in follow-on projects in collaboration with partners such as NXP, TomTom and Technolution and running on the C-ITS corridor developed by the Dutch road operator Rijkswaterstaat.

Research on control design typically aims at providing methodology, toolbox, and insights into design and assessment of automate driving systems and has the potential to improve roadway capacity and

safety when applied in reality, and is funded by amongst others STW, Toyota and FHWA. Authority transitions between the driver and vehicle were studied in a field experiment in collaboration with BMW.

Research on automated driving as a mobility service is conducted in collaboration with the public transport sector and regional (Province of Gelderland) and city authorities (ProRail) because of the relevance to last-mile transportation and collective transport in sparsely populated areas and its potential to reduce transport costs, congestion and pollution. T&P used the theoretical work on implications of automated driving to develop scenarios for automated driving for the Dutch Environmental Planning Agency and in a study how to integrate automated driving in the Dutch National Transport Model.

Theme D: Active Mode Mobility
Next to scientifically challenges, active mode mobility – in particular in an urban context – is a societally very relevant theme. While many Dutch cities have seen a considerable increase in the share of transport by bicycle, having strong impact on health, accessibility, and liveability of a city, municipalities have to ensure that the attractiveness of using a bike remains at the current level or even improves. This means carefully considering infrastructure and network design, as well as looking for innovative solutions in realm of traffic control and ITS. At the same time, different cities in the Netherlands and abroad are looking for ways to increase bike shares, which also entails looking at specific groups in society that are not using the bike on a day to day basis.

Regarding pedestrian flows, typical societal issues are overcrowding of stations and city centres (e.g. during events, or due to large groups of visitors). Within this theme, a key focus is to support stakeholders in the design and management of pedestrian infrastructure in order to keep the city a safe and comfortable place to be in. The societal impact of the research in this theme is thus large. Next to the fact the different applied projects have been conducted on behalf of municipalities or organisations such as SAIL, many outreach activities have been conducted. These include traditional ways, such as providing public lectures and keynotes, but also participation in or chairing of scientific councils (including the Dutch scientific council "Veilig Ontrumen" and the TRB subcommittee "Crowd Modelling and Management").

The group is collaborating actively with stakeholders such as ID&T (concert organisation), TSC (The Security Company), NS Stations (crowd management in railway stations), InControl (crowd simulation software) and Goudappel (active mode modelling). With the latter two, MoU's where signed in 2015 to further collaboration on this novel research theme.

1.5 Viability

The traffic and transportation engineering field is changing. Economic, demographic and technological development is leading to strong urbanisation world-wide. New traffic and transport-related research challenges will typically be embedded in a smart city context. Societal issues related to traffic and transport are manifold: they include sustained travel time delays and unreliability in transport networks in urbanised areas, overloading of the train stations during peak hours, massive (and sometimes high-risk) pedestrian flows during events, lack of connectivity of public transport and the high demand on cycling infrastructure. Through the core application areas, T&P is well-positioned to develop the scientific theories, methods and applications to address these issues. In addition, we will foster the overlap between our core application areas to increasingly develop integrated theories and approaches. University-wide initiatives such as the Amsterdam Institute for Advanced Metropolitan Studies (AMS), Leiden Univ.+ Delft Univ. of Techn. + Erasmus University Rotterdam (LDE) and Delft Deltas, Infrastructures & Mobility Initiative (DIMI) and our international academic network provide us with excellent networks with large urbanised regions in the Netherlands as well as world-wide.

Theme A: Coordinated and Cooperative Network Traffic Operations and Management
Traffic Management is moving into a new era. A core element here is the integration of roadside and car-based traffic management for data collection and state estimation and for control. For a successful deployment, multilevel, multi-scale and multimodal traffic state estimation, prediction and management methods will have to be developed, which is especially challenging for large areas. The foreseen approach may use self-organising as well as hierarchical control concepts to address emerging complexity, exploit increasing abundance of data and analyse traveller and driver behaviour. This research will build on the Amsterdam Practical Trial. The use of connectivity to enhance situational awareness at all driving tasks level and the increasing level of vehicle automation will require to fundamentally re-assess traffic flow fundamentals and management concepts. This research avenue will build on a previous study of twenty instrumented vehicles to investigate driving behaviour and long-term changes therein due to advanced driver support systems, recent work into cooperative vehicle control algorithms and current work focusing on transitions between different levels of vehicle automation. Special attention in this research theme will be on emergency situations (e.g. flooding in case of heavy rainfall or a breach of a dike) and the design of a resilient traffic and transportation (management) system (in collaboration with the Water Management programme at our Faculty of CEG).

Theme B: Reliable Multimodal Transport Systems
T&P has established a firm scientific basis in the field of reliable multimodal transport systems that will allow us to address the scientific challenges in the field that lie ahead. The international visibility and impact –already apparent from our publications in high-ranked journals- will further grow as a result of successful project acquisition leading to the appointment of some 15 PhD researchers. T&P is now well-positioned to address revolutionary changes such as the migration of the railways to ERTMS, emerging trends in ICT and automation as well as lifestyle and economical changes, congestion and resilience of public transport systems, the impact of service disturbances and major disruptions on passengers' flows, and shared mobility. Our research will continue to address multimodal dynamic modelling, with increased attention to activity based modelling, dynamic network modelling and the use of big data. In 2016, the staff will be extended with full professors on railway traffic management, on freight transport and logistics, and intermodal and synchromodal freight transport. The latter is expected to increase the number of PhD researchers in this field. Given the close relation to external programmes and agenda's, we anticipate that sufficient funding opportunities will be available.

Theme C: Cooperative and Automated Driving
Research into cooperative driving will be continued into both fundamental lane-based traffic flow dynamics & control and driver motivation and compliance in the newly acquired STW project "Taking the Fast lane", in close collaboration with industrial and public stakeholders. In collaboration with Technolution, swarm-based intelligence will be studied to enable decentralised traffic flow control. With further improving connectivity between vehicles and roadside systems, the TU Delft test vehicle is being equipped to provide empirical data. Research into control algorithms will continue into integrated longitudinal and lateral control in recently acquired STW and CSC-funded projects, also using the TU Delft test vehicle in real life. Increasingly, research will be focused on automated driving at bottleneck situations and in different roadway design such as dedicated lanes. Future research into human factors and traffic safety will be continued in collaboration with SWOV and international industrial partners and focus on both authority transitions and traffic safety of highly automated driving shared space, including the interaction with pedestrian and cyclists. Research into automated driving as a mobility service will be aimed at large-scale systems where vehicles are available in a whole urban area providing accessibility to multiple activities and social contexts, and also include user acceptance and implications for parking. Research into the implications of automated driving will focus on understanding and assessing long-term implications of automated driving (e.g., travel and location choices, land uses, transport infrastructure) as well as on re-designing existing infrastructures under the perspective of automated driving. This research will be conducted within newly acquired projects (STAD, DRAGON, Self-driving city) and in forthcoming research projects (e.g. CARTRE; Coordination of Automated Road Transport Deployment for Europe). Synergies of vehicle automation with other mobility innovations (e.g., sharification, electrification) are emerging research lines of T&P in this field.

Theme D: Active Mode Mobility
A major challenge in contemporary traffic and transportation theory is having a comprehensive understanding of pedestrians and cyclists' behaviour. With active traffic modes gaining ground in terms of mode share in many cities, lack of empirical insights, behavioural theories, predictively valid analytical and simulation models, and tools to support planning, design, management and control is posing a major societal problem. Current work

focuses on generalising theories and methods to pedestrian and bicycle traffic and transport, while at the same time broadening the theme's scope with topics such as advanced data collection and data fusion for real-time estimation, activity scheduling and route choice, and network knowledge acquisition and memory decay. A large share of this work will be performed within the scope of the ERC Advanced Grant project Allegro (Hoogendoorn), and within the mobility stream of the AMS Institute. The research will be geared towards a comprehensive theory of slow mode traffic behaviour, considering walking and cycling operations, activity scheduling and travel behaviour, and knowledge representation and learning. Major scientific breakthroughs are expected at each of these levels, in terms of theory, modelling and management, by using innovative (big) data collection and experimentation, analysis and fusion techniques, including social media data analytics, using augmented reality and remote and crowd sensing.

1.5.1 BENCHMARK: ETH ZÜRICH

Given the appointment of several new staff members and the intention to provide staff members with increased autonomy, responsibility and accountability, a benchmark visit was performed at the Institute of Transport Planning and systems (IVT) at ETH Zürich headed by Prof. Kay Axhausen, for its international reputation and scientific excellence and a strong 'PI' structure. The aim of the benchmark was to learn the pros and cons of the ETHZ PI Structure.

In the ETHZ tenure-track system, assistant/associate professors are hired as PI ('chair') with the intention that they become full professors in 6 years. With good working conditions (salary, quality of life, independence) and generous start-up packages, ETHZ is able to attract top scientists. The chairs are independent and limited coordination mechanisms exist between them.

Leadership at ETHZ lies at a single chair, who is able to develop and execute a long-term research strategy and has basic funding to appoint PhD researchers. ETHZ has no graduate school. Progress monitoring of PhD-candidates occurs at the discretion of the chair. In the group of Prof. Axhausen the activity-based transport model 'MATSIM' is the main foundation and integrating element of the research projects. It is not only used in the ETHZ-IVT research, but also in a wider international academic community. Nevertheless, large-scale research facilities or large practical pilots, which would offer research opportunities for even larger groups or researchers, are often not within the reach of what a single chair can do. This provides limitations to make a societal impact, other than via collaborating with industry.

The pros of the PI structure in place at ETHZ are a strong alignment of scientific strategy, responsibility and accountability, and excellent basic funding conditions. The cons are the dependability on a single person and the limited economies of scale. These findings support the direction of development of T&P (in line with the new strategic framework of TU Delft). Leadership will reside at a collective of different individuals with different levels of scientific stature, allowing increased autonomy, responsibility and accountability. The research strategy is based on a common vision on fundamental research and core application fields. A coherent set of research tools and datasets provides economies of scale, flexibility and robustness. Collaboration and debate takes place in smaller teams (clusters, task forces or labs) based on the core application areas.

1.5.2 SWOT

1.5.3 STRATEGY FOR THE FUTURE

The strategy of the T&P programme for the coming years is aimed at further strengthening its position as a world-leading group in transport research. During the assessment period, T&P has reinforced its scientific basis by establishing a young, vibrant and talented scientific team. T&P will reconsider its organisational model in order to support and recognise more autonomy at young scientific staff, whilst reducing the managerial burden at senior staff. Internal collaboration, information exchange and scientific debate will be further developed along 'clusters, task forces and labs' based on the core application areas.
Increasingly, we aim to develop scientific research projects in smart-city, multi-domain collaboration. We envisage Smart Urban Mobility and Logistics to form a new connecting element in our future research, with a strong emphasis on empirical research and new data collection and information processing methods, via DiTT-Lab, but also via the newly founded RADD (Researchlab Automated Driving Delft) and UMO (Urban Mobility Observatory) platforms.

SWOT of the Transport & Planning programme

Strengths	**Weaknesses**
• Strong research tradition and scientific signature • Large and broad coverage of domain, critical mass • International recognised top researchers • Young scientific staff • Strong internal social cohesion • Excellent mix of fundamental and application-oriented research and research funding acquisition • International visibility and high exposure, • International clients • Strong empirical laboratory facilities • Strong TU Delft coalitions: TI/DIMI, Faculties CiTG, 3mE, TBM, EWI, Architecture	• High managerial burden on senior researchers / full professors • Duration of PhD projects
Opportunities	**Threats**
• Research field expanding in relevance and diversity due to urbanisation, increasing role of connectivity, electrification and automation • Involvement in smart city, multi-domain initiatives (AMS, Connekt, Smart Mobility Embassy, DCE, MRDH) • Strong strategic partners: RWS, TNO, SWOV, Goudappel, ProRail, Port of Rotterdam, InControl • Good match with national research priorities: top sectors, and National Research Agenda. Potential for large national programmes such as NWO-Gravitation • H2020 funding, EU networks CARTRE, hEART • Collaboration with China • Introduction of ius promovendi for associate professors • Increasing possibilities for multidisciplinary crossover such as mathematics and information science.	• Lack of formal autonomy and accountability for young scientific staff • Decreasing research funding at the national level • International battle for talent

Our funding strategy will continue to focus on personal grants from NWO and ERC, collaboration in consortia (smart cities, KIC Urban Mobility, H2020), and international research programmes in collaboration with Monash University and Chinese universities such as Tongji and BJTU. Regarding our presence in EU-funded research, new EU-funded projects SETA, MyTrac, SAFE10T were already acquired in 2017 and many new proposals are being developed.

Regarding further extension of the scientific staff, in 2017, Rob Goverde was already appointed as full professors in Railway Traffic Management and Operations and a new staff member on this field is being recruited. In addition, Dorine Duives was appointed in the field of active modes.

We will work to reduce the duration of PhD projects by more stringent supervision and a stronger selection of PhD candidates.

Water Management programme

1.1 Research area and objectives

1.1.1 MISSION

The mission of the Water Management programme is formulated as "Performing innovative research and (advanced) education in hydrological and urban water cycles related to societal relevant themes".

1.1.2 OBJECTIVES

The objectives of the research are to understand water availability and water use, as well as water quality, treatment and transport, and to translate this knowledge into practical technologies and methods. This includes decision-making in flood control, drought mitigation, water quality and ecosystem management, and equip the water sector with technology to provide high-quality water at acceptable costs, collection and conveyance of used urban water, and adequate treatment of polluted water to stringent criteria for discharge or reclamation. The programme especially focuses on the development of novel measurement methods for different components of the water cycle (evaporation, groundwater out flow, illicit connection in urban drainage), new data analysis methods and flexible modelling approaches for processes related to water availability and water use. In addition, the programme has a particular strength in technology development based on membrane separation techniques as used in the treatment of drinking water, wastewater and sludge, as well as in water reclamation and the removal of inorganic pollutants from groundwater.
Finally, the programme aims at research using a combination of refined laboratory methods and on-site testing to ensure the feasibility of the developed technologies, balancing fundamental and applied aspects, both in Europe and overseas (especially Africa and Asia), where managing water resources and water treatment reliability is of particular societal impact.

1.1.3 FOLLOW-UP OF THE RESEARCH ASSESSMENT 2005-2010

During the last research assessment, it was stated that the programme was in a transition phase with a large proportion of contracts, instead of research grants, and a large number of PhD students relative to the permanent staff. In addition, it was suggested to reconsider the publication strategy. It was then also concluded that, while the societal

Table 1. Research staff 2011-2016 for the Water Management programme.

Water Management	2011		2012		2013		2014		2015		2016	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	41	8,9	42	10,2	43	10,8	42	10,7	42	10,9	43	11,3
Researchers (2)	30	12,2	32	7,4	35	7,3	47	14,4	38	16,5	53	22,3
PhD candidates (3)	126	72,7	141	83,4	151	87,5	152	89,1	154	82,9	163	86,5
Total Research staff	197	93,7	215	100,9	229	105,6	241	114,1	234	110,4	259	120,1
Support staff	2	0,2	2	0,2	6	0,9	11	1,5	6	0,9	4	0,8
Total staff	199	93,9	217	101,1	235	106,5	252	115,6	240	111,2	263	121,0

(1) comparable with WOPI category HGL (full professor), UHD (associate professor), UD (assistant professor), tenured and non-tenured
(2) includes post-docs and temporary postgraduate researchers
(3) includes all PhD categories

Top: segment of the water lab
Bottom left: balloon sensors used in the Irrawaddy river
Bottom right: sensors designed for trees in the Amazon

relevance of the research is clear, the direct input to policy-making at various levels was less obvious and that there was limited evidence of research into the socio-economic aspects. Now, the programme is much more in balance, in terms of staff, funding and publications. We stabilised the number of PhD students, increased the number of talented, young, permanent staff members and attracted a considerable number of research grants, diminishing the dependence on contracts. The high-level research resulted in high-impact publications and personal research grants.
We are also aiming at the use of the scientific products in society. Therefore we have co-operated intensively with companies and societal organisations. This has even led to some spin-off companies who have received NWO-supported valorisation grants. Our strategy for the dissemination of results is currently based on open-access publication of papers and data, accessible for societal organisations and companies. Examples of co-operation with societal organisations/companies are the five strategic MoUs that have been signed by the programme with water companies, and the Dutch umbrella organisation on urban drainage.

1.2 Organisation of Research

1.2.1 RESEARCH THEMES

The research themes of the Water Management programme are linked to the core applications and connected to the overall mission. The following core application fields (themes) have been identified:

A. Observation & modelling of water resources;
B. Water quality, treatment & reclamation;
C. Urban water systems;
D. Monitoring & control of water processes.

Table 2: Contributors to the core application fields.

	H-index (Scopus November 2017)	Observation & modelling of water Resources	Water quality, treatment & reclamation	Urban water systems	Monitoring & control of water processes
Edo Abraham	6				●
Mark Bakker	17	●		●	●
Thom Bogaard	18	●	●		
Boris van Breukelen	22	●	●		
Mirjam Coenders	8	●			
Maurits Ersten	8	●			
Nick van de Giesen	29	●		●	●
Doris van Halem	8		●		●
Bas Heijman	23		●		
Marcus Hrachowitz	25	●			
Merle de Kreuk	18		●		
Jules van Lier	43		●	●	
Ralph Lindeboom	5		●	●	
Erik Mostert	15	●			
Ronald van Nooyen	6	●			●
Saket Pande	8	●		●	
Luuk Rietveld	20		●	●	●
Martine Rutten	6	●	●		●
Huub Savenije	49	●			
Lisa Scholten	5			●	
Gerrit Schoups	19	●	●		
Henri Spanjers	21		●		●
Susan Steele Dunne	13	●			
Marie-Claire ten Veldhuis	8	●		●	

Measuring plant thirst

Susan Steele-Dunne

In areas where water is scarce, people prefer to only water plants when it is really necessary. Soil moisture is the main source of water for vegetation. Unfortunately, plants and trees get in the way of measuring soil moisture. Normally researchers try to filter out the noise caused by vegetation, but Susan Steele-Dunne studies moisture concentrations in plants using radar measurements. Knowing the moisture levels in crops could also provide insight in soil moisture.

www.tudelft.nl/en/ceg/research/stories-of-science/measuring-plant-thirst/

The research themes are connected through a common approach based on fundamental research into functioning of water systems in all its complexity. Researchers with various backgrounds work in these themes, stimulating interdisciplinary research and innovation.

1.2.2 STAFF

Table 1 contains an overview of the research staff 2011-2016, while Table 2 provides an overview of the individual researchers and to which research theme they contribute. Since 2011 we appointed seven new tenure-track assistant professors to increase the full time research capacity for research and education. In addition, the large number of PhD students contributed to a high research output, in terms of awarded PhDs and peer-reviewed papers in highly ranked journals.
The programme has a close cooperation with UNESCO-IHE, resulting in a large number of their PhD candidates being registered in our programme. Their share has grown from 24% in 2011 to 32% in 2016.

1.2.3 FACILITIES

The programme makes use of part of the WaterLab at Stevin III, Civil Engineering building. The facilities were recently expanded and upgraded. A completely new anaerobic lab has been established, measurement equipment has been purchased and facilities for bench scale and pilot testing have been installed.
The laboratory is organised at the programme level and run by two supporting staff members, under supervision of a lab committee, consisting of three academic staff members. The laboratory investments support the PhD students and stimulate BSc and MSc students to perform more experimental work. Some of the facilities are fully automated, allowing remote monitoring and control via laptop or smartphone devices. The laboratory facilities are also used to store and test equipment needed for fieldwork, which is an integral part of our research focus. The costs of the laboratory facilities are partly (25%) paid by project funding.

1.2.3 FUNDING

The strategy of the Water Management programme is to obtain a balanced portfolio of direct funding, research grants and contract research (see Table 3). The contribution of contract research decreased during the evaluation period and the contribution of research grants (e.g. NWO, STW) increased, which is in line with the strategy of the programme on the one hand and induced by changes in governmental policies on the other hand. All scientific staff members are responsible for acquiring their own project funding, in line with their field of expertise. Junior staff members are coached by the more experienced ones, and funding strategy is discussed during yearly evaluation meetings (R&D cycle).

Table 3: Overview of the funding en expenditures of the Water Management programme.

Water Management	2011		2012		2013		2014		2015		2016	
Funding:												
Direct funding (1)	3.551	41%	3.119	37%	3.399	43%	3.879	48%	3.747	49%	3.806	52%
Research grants (2)	85	1%	510	6%	643	8%	1.006	12%	835	11%	1.338	18%
Contract research (3)	4.838	56%	4.848	57%	3.762	48%	2.968	36%	2.604	34%	1.798	25%
Other (4)	236	3%	38	0%	52	1%	280	3%	430	6%	363	5%
Total funding	8.710	100%	8.515	100%	7.856	100%	8.134	100%	7.616	100%	7.305	100%
Expenditure:												
Personnel costs	5.553	71%	5.785	70%	5.726	74%	5.999	77%	6.000	77%	5.638	78%
Other costs	2.254	29%	2.527	30%	1.994	26%	1.767	23%	1.770	23%	1.547	22%
Total Expenditure	7.807	100%	8.312	100%	7.720	100%	7.765	100%	7.770	100%	7.185	100%

Note 1: Direct funding (basic funding / lump-sum budget)
Note 2: Research grants obtained in national scientific competition (e.g. grants from NWO and the Royal Academy)
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

1.2.4 MANAGEMENT OF PROGRAMME

The research programme is led by a management team consisting of the Head of Department, two section leaders and the executive secretary, who meet monthly. In addition, a yearly strategic meeting is organised with all scientific staff members. Research initiatives are exchanged and discussed during bi-yearly section meetings. Finally, every three months, meetings are organised on specific research topics, discussing and preparing for funding opportunities.

1.3 Scientific quality

Below, the main scientific results are described for each of the above-mentioned research themes, followed by a summary table of the scientific output. As indicators for scientific quality the following topics were chosen: citations of individual articles; H-index; use of products by peers; scientific awards; prestigious personal grants; editorship; and keynote lectures.
The research is published in the internationally leading scientific journals in the discipline and received substantial attention with a high number of citations. In addition, 110 dissertations were published and the full-time staff members are internationally recognised, as illustrated by scientific awards, personal grants (NWO-Veni and Vidi) and high H-indices (see Table 2).

1.3.1 RESEARCH THEMES

Theme A: Observation & modelling of water resources

Research on catchment hydrology concentrates on an innovative approach to better understand, model and predict hydrological processes at catchment scale. The main innovation is the landscape and ecosystem-based approach that allows model concepts to be transferred between different catchments with minimum calibration, making use of a Darwinian approach to determine root zone storage. In addition, we have developed dual-permeability models and applied them on meso-scale hill-slope hydrological case studies to study the response to rainfall and associated slope stability.
Globally 55-80% of the precipitation evaporates annually from the land, making it the largest water consumer of our water resources. However, evaporation observations are limited, which results in a poor understanding of the evaporation process (Coenders-Gerrits et al., 2014). We developed a new method, where, with DTS cables, temperature and humidity profiles can be measured, to quantify evaporation. Additionally, information is obtained on the heat storage and fluxes, and on the source of evaporation (i.e. transpiration, interception, soil evaporation). This research was funded by an NWO-Veni personal grant. In addition, we make use of innovative stable water isotopes' measurements, which teach us how water is transported from the unsaturated zone, through the plant, back to the atmosphere. A new data assimilation algorithm was developed to obtain high-resolution estimates of the soil moisture and temperature profiles. Data assimilation has also been used to assimilate different remote sensing observations (LST, soil moisture, GRACE) into hydrological models. Finally, radar has been used to monitor canopy water dynamics for the early detection of water stress (Steele-Dunne et al., 2017) Field observations using an innovative custom-built sensor highlighted the vertical and temporal variability in canopy water storage that is not accounted for in current models and applications. This research was funded by NWO-Veni and Vidi personal grants.
To be able to measure groundwater velocity, and thus better predict subsurface flow, a novel method was developed using a heat tracer experiment, making use of DTS along fiber optic cables (Bakker et al., 2015). The groundwater velocity was derived from the rate of heating and cooling of the groundwater. Results of the feasibility study resulted in a grant from NWO to continue development of the method. In addition, new techniques were developed to simulate measured temporal variations in the groundwater head. An open-source computer programme was developed to analyse the incredible amount of data in the Netherlands and around the world. Special attention is given to observation and modelling of water resources using poorly exploited sources of information such as remote sensing and citizen science in data scarce areas for applications ranging from water quality and land use to erosion/sedimentation. Recent developments of smartphone application to measure rainfall, water levels, water and air quality is boosting and are advantageous in Citizen Science projects. The scientific challenge lies in the quality assessment of data collected by non-professionals. An example is the development of approaches for sediment load and introducing biomonitoring as a new citizen science tool in Myanmar, investigating the technical as well as the social aspects. We systematically tested the quality of citizen science data collection and showed it is possible to independently guard the quality of such data.

Selected publications:

- Coenders-Gerrits, A.M.J., Van der Ent, R.J., Bogaard, T.A., Wang-Erlandsson, L., Hrachowitz, M., and Savenije, H.H.G. (2014). Uncertainties in transpiration estimates, Nature, 506, E1-E2.
- Sivapalan, M., Savenije H.H.G., and G. Bloeschl, (2012) Socio-hydrology: A new science of people and water, Hydrological Processes, 26, 1270-1276 doi: 10.1002/hyp.8426
- Steele-Dunne, S. C., McNairn, H., Monsivais-Huertero, A., Judge, J., Liu, P. W., Papathanassiou, K. (2017). Radar Remote Sensing of Agricultural Canopies. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing , P(99): 1-25.
- Donchyts, Gennadii, Fedor Baart, Hessel Winsemius, Noel Gorelick, Jaap Kwadijk, Nick van de Giesen (2016) Earth's surface water change over the past 30 years. Nature Climate Change, 6(9) :810-813.
- Bakker, M., Caljé, R., Schaars, F., Van der Made, K.J., De Haas, S. (2015). An active heat tracer experiment to determine groundwater velocities using fiber optic cables installed with direct push equipment. Water Resources Research, 51(4), 2760-2772.

Theme B: Water quality, treatment & reclamation

Wastewater treatment for environmental protection is developing towards technologies that focus on resource efficiency and recovery, for its use in the bio-based economy. Research has been focused on the development of anaerobic membrane bioreactors (AnMBR) for the high-level treatment of organically polluted wastewaters with concomitant energy recovery (Dereli et al., 2012) . Application of AnMBR technology under extreme conditions (salinity, temperature), potentially inhibiting anaerobic bacteria, drastically widens the application potential of anaerobic treatment in general (Muñoz Sierra et al., 2017). The research funded by STW-NWO resulted in e.g. a good conversion of phenol (up to 99%) with temperatures and salinity of up to 55oC and 36 gNa/L, respectively. In the past 5 years, about 20 invited key note lectures were given at international conferences high-lighting the novel advancements in anaerobic technology for the purpose of resource recovery, included the treated water itself.
To underpin the above challenges of resource recovery, biotechnological and physical mechanisms were investigated underlying anaerobic digestion, hydrolysis processes and performance of (aerobic) granular sludge systems. The composition, characteristics and conversion of complex substrates, e.g. waste activated sludge (WAS), were unravelled to improve the (process) design of sewage treatment plants and digesters. Pre-treatment ranges from enzymatic treatment, aquatic worm predation or high and low temperature treatment. As one of the first, an odd numbered volatile fatty acids (VFA) dominated spectrum, was produced at relatively high pH and 30oC, with granular fermentative sludge. Research to the removal and conversion of suspended solids from sewage in a so-called Nereda® system (aerobic granular sludge) was awarded with an NWO-Vidi personal grant in 2016. Novel Magnetic Resonance Imaging (MRI) is used to study and visualise the complex interior of and measure transport phenomena in the granules during the conversion of the contaminants.
Innovative membranes have been developed for their application in water treatment and reclamation purposes (Shang et al., 2014). Ceramic membranes, with low fouling potential and high fluxes, have been tailor-made by a patented atomic layer deposition (ALD) process, as such the pore sizes of the substrate were narrowed, until nanofiltration scale, even rejecting molecules of 300 Dalton, having a potential for the direct treatment of raw sewage, opting for water reclamation. For this research, competitive NWO-STW funding was obtained.
Drinking water treatment is coping with a wide range of new, emerging contaminants, as well as with stricter guidelines for safer water around the world. Key focal points of our research have been the removal of arsenic to concentrations below 1 µg/L with aeration and rapid sand filtration (NWO-STW-funded) (Gude et al., 2016), as well as arsenic removal during high temperature nanofiltration, and elucidating the kinetic limitations of arsenic sorption during small-scale sub-surface treatment (NWO-WOTRO funded); all researches with promising, well-documented results.
For the prediction of the fate of pollutants in the environment, models have been developed and applied for quantifying and predicting pollution in rivers and aquifers. A reactive transport model for simulating long-term behaviour of in-situ permeable reactive barriers for cleaning up groundwater contaminated

Observing rain at street-level

Marie-Claire ten Veldhuis

Heavy showers sweep over cities, flooding streets and houses when urban drainage systems get overwhelmed. We're currently unable to predict accurately where and when flooding will occur. Forecasting is particularly tricky in densely populated cities. Researchers want to use radar and innovative ground sensors to observe rainfall and water levels more accurately to improve the reliability of hydrological predictions . Marie-Claire ten Veldhuis'objective is to unravel the complexity of urban hydrological response, to be able to predict with greater accuracy when and where streets will flood.

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with chlorinated solvents was developed. Modelling has also been expanded to physical-chemical processes in engineered groundwater systems, advancing reactive transport modelling (PHREEQC) to elucidate the controlling of biogeochemical processes and thereby assess and optimise their site-specific performance or environmental impact (Van Breukelen et al., 2016). A key scientific result is the development of a mechanistic model on thermal arsenic desorption. The research has been funded by highly competitive NWO (UDW, Topsector Water) and EU (Marie Curie ITN) research programmes.

Selected publications:

- Dereli R.K., M.E. Ersahin, H. Ozgun, I. Ozturk, D. Jeison, F. van der Zee, and J.B. van Lier (2012). Potentials of anaerobic membrane bioreactors to overcome treatment limitations induced by industrial wastewaters. Biores. Technol. 122: 160-170.
- Muñoz Sierra J., Lafita, C., Gabaldón, C., Spanjers, H., Van Lier, J.B. (2017). Trace metals supplementation in anaerobic membrane bioreactors treating highly saline phenolic wastewater. Bioresource Technol. 234: 106-114.
- Shang, R, Verliefde, A.R.D., Hu, J., Zeng, Z., Lu, J., Kemperman, A.J.B., Deng, H., Nijmeijer, K., Heijman, S.G.J., Rietveld, L.C. (2014).Tight ceramic UF membrane as RO pre-treatment: The role of electrostatic interactions on phosphate rejection. Water Research, 48 (1): 498-507.
- Gude, J.C.J., L.C. Rietveld, D. van Halem (2016) Fate of low arsenic concentrations during aeration-filtration. Water Research: 88 566-574, DOI: 10.1016/j.watres.2015.10.034.
- Van Breukelen, B.M.; Bonte, M., (2016). Comment on "Thermally Released Arsenic in Porewater from Sediments in the Cold Lake Area of Alberta, Canada". Environmental Science & Technology, 50: 7263-7264.

Theme C: Urban water systems

The research in water distribution has focused on improving the efficiency of systems through discolouration risk management, and leak identification and reduction. Developing tailored mathematical optimisation tools for pressure management, and associated design problems has supported the work. Similarly, by devising new mixed-integer optimisation and graph theoretic algorithms, approaches were presented for determining optimal configurations for self-cleaning water distribution systems and optimal placement of pressure reducing valves and isolation valves. Simulation and practical testing of leak localisation with different demand models and monitoring systems (including remote sensing) led to novel insights for model selection and the design of leak-localisation campaigns.
Our research into urban hydrology showed that hydrological response in urban systems is sensitive to small-scale rainfall variability, in space and especially in time, indicating that the resolution of current operational rainfall radar products is insufficient for urban flood prediction. Analysis of flood observations datasets based on citizens' reports has shown that proximity to drainage outlet and variability in impervious surface cover, play a significant role in explaining flood occurrence, while the role of variability in rainfall intensity could not be confirmed at the available data resolution (Ochoa-Rodriguez et al., 2015). We analysed insurance claims of flood damage and found that failure of in-house storm water drainage facilities, caused the largest number of damage claims. Claims associated with flooding from urban drainage systems, led to significantly higher damage amounts than failure of in-house drainage systems (Veldhuis et al., 2011).
For new sanitation concepts, based on flow separation, research is being performed related to the transport of thick domestic slurries in pressurised sewer pipes, funded by NWO-STW. Research so far showed the impact of concentration and temperature of these slurries on the hydrodynamic behaviour of the slurry, which will set the boundary conditions for the transportability over large distances.
In addition, the research on methods and processes for multi-stakeholder water infrastructure planning support has focused on the development of an analytical framework to identify barriers to water infrastructure innovation (Scheidegger et al., 2015). It proved suitable to detect key barriers in selected cases and indicates potential links to innovation project success.
In 2016 three projects in the NWO-STW TISCA (Technology programme for sewer condition assessment) programme have been awarded, being Fast Over-all scanning of Underground and Linear Constructions (FOULC), Geo-Electrical Sewer Leak Detection, Quantification and Location, and Sewer Sense – Multi-sensor condition assessment for sewer asset management.

Selected publications:

- Ochoa-Rodriguez, S., Wang, L-P., Gires, A., Pina,

Water management, Water lust and nuisance

Jules van Lier

In the Netherlands we are used to reliable and good quality drinking water from the tap, proper waste water treatment and dry feet. But the KNMI meteorological institute is predicting that before the century is out the country will suffer an increase in extreme rainfall due to global warming. The infrastructure of our cities' water systems do not have the capacity to process these amounts of water, Jules van Lier warns. He argues that what we need are smart solutions and a new paradigm for the Urban Water Infrastructure.

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R.D., Reinoso Rondinel, R.R., Bruni, G., Ichiba, A., Gaitan Sabogal, S., Cristiano, E., Assel, J. van, Kroll, S., Tchiguirinskaia, I., Onof, C., Willems, P. & Veldhuis, J.A.E. ten (2015). Impact of spatial and temporal resolution of rainfall inputs on urban hydrodynamic modelling outputs: A multi-catchment investigation. Journal of Hydrology, 531(2), 309-407.

- Veldhuis, J.A.E ten (2011). How the choice of flood damage metrics influences urban flood risk assessment. Journal of Flood Risk Management 4.4 (2011): 281-287.
- Scheidegger, A., Leitao, J.P., Scholten, L. (2015) Statistical failure models for water supply pipes – a review from a unified perspective. Water Research 83 237-247.

Theme D: Monitoring & control of water processes

Our group has been a clear pioneer and developed many new monitoring applications. The scientific success is probably best measured through the impact that DTS has had over the past ten years in environmental sciences (Giesen et al., 2012). The Trans-African Hydro-Meteorological Observatory (TAHMO) is a more recent but even more ambitious development in which we seek to install and operate a dense network of 20,000 weather stations across sub-Saharan Africa. The computation aspects come to the fore in the eWaterCycle project, which is the first global operational forecasting model with high resolution, data assimilation, and lateral movement of water.

Monitoring and control research in the drinking water supply was concentrated around the development of a simulator of a drinking water treatment plant for operation and training purposes. Therefore integration of models and platforms was needed and new algorithms were developed to rapidly exchange information. In addition, models were developed for the prediction of drinking water use to operate the system energy-efficiently (Bakker et al., 2013). New algorithms were made to identify pipe bursts in real time with limited data and adaptive calibration, taking into account accuracy of prediction and size of the burst in relation to size of the area.

The role of pumping systems in the urban water-energy nexus has been studied by assessing the feasibility of demand response from water distribution systems for electricity grids, under the current energy markets, and by investigating the optimal inclusion of different intermittent renewable energy sources (Menke et al., 2016). This has also enabled scalability and numerical reliability for large-scale water systems. This has motivated work on global optimisation tools for pump scheduling under demand uncertainty. In addition, multi-objective optimisation tools were developed.

With respect to the control of wastewater treatment, a sensor based on mid-infrared spectroscopy was developed, optimised and tested in the lab and on full scale for its ability to monitor the VFAs' concentration in industrial anaerobic digesters. An anaerobic digestion model was developed to describe the sulphate reduction process in the digestion of very high strength and sulphate-rich industrial vinasse streams. The model was validated against experimental data and used for life-cycle assessment and exergy analysis of anaerobic digestion power plants. In addition, a model was developed to describe the biochemical conversion of starch in paper pulp into VFAs, making use of PHREEQC modules. The purpose was to predict the effect of VFA production on the scaling potential of the water in a paper mill using recycled paper and recycled water. The model was able to predict observed acidification and scaling.

Selected publications:

- Van de Giesen, N., Steele-Dunne, S., Jansen. J., Hoes, O., Hausner, M. B., Tyler, S., Selker, J. (2012). Double-Ended Calibration of Fiber-Optic Raman Spectra Distributed Temperature Sensing Data. Sensors, 12(5):5471-5485.
- Menke R., Abraham E., Parpas P, Stoianov I. (2016), Demonstrating demand response from water distribution system through pump scheduling, Applied Energy, Vol: 170, Pages: 377-387, ISSN: 0306-2619.
- Bakker, M., Vreeburg, J.H.G., van Schagen, K.M., Rietveld, L.C. (2013). A fully adaptive forecasting model for short-term drinking water demand. Environmental Modelling and Software 48 Pp 141-151.

1.3.2 RESEARCH OUTPUT

The output of the research can be characterised by peer-reviewed papers in highly ranked journals (see selected publication above and Table 4) that finally end-up in a dissertation (see section on PhD candidates). From Table 4 we can conclude that over the years less emphasis is given to conference publications and more to higher impact peer-reviewed journal publications. The number of dissertations is kept

Table 4. Main categories of research output of the Water Management programme.

Water Management	2011	2012	2013	2014	2015	2016
Refereed articles	135	152	147	180	160	154
Non-refereed articles (1)	9	2	2	2	1	8
Books	1	3	0	0	0	1
Book chapters	8	9	6	7	5	2
PhD theses	17	13	17	21	22	20
Conference papers	91	77	43	52	26	18
Professional publications (2)	23	30	35	18	10	6
Other research output (3)	100	75	185	226	175	133
Total publications	384	361	435	506	399	342

Note 1: Articles in journals that are non-refereed, yet deemed important for the field
Note 2: Publications aimed at professionals in the public and private sector (professionele publicaties), including patents and annotations (e.g. law)
Note 3: Other types of research output, such as patents, book reviews, editorships of books, editorships of journals, inaugural lectures, abstracts, designs / prototypes, appearances on radio or television, "populariserende artikelen" and other research output (internal reports, lectures)

stable, at a relatively high level for the number of faculty members. We stimulate our PhD candidates to attend a conference to present their research by a (poster) presentation at least once per year. Hereafter, the research is published as a refereed article.

1.3.3 PHD CANDIDATES

Our acceptance policy of new PhD candidates (with scholarships) has been more formalised and stricter. This is partly due to the introduction of the TU Delft Graduate School, see also the general report of Faculty. PhD candidates should have an adequate level of English and bring along tuition and bench fee, if a supporting project is not available. Since the start of the TU Delft Graduate School, structure and more systematic supervision is given, consisting of a team of a daily supervisor, also being the co-promotor, and the promotor. These changes resulted and will result in the reduction of the duration of PhD trajectories. From Table 5 it can indeed be observed that the percentage of discontinued PhD students dropped considerably and that the percentage of PhD students graduated after <=5 years gradually increased to about 50%.

1.3.4 RECOGNITION

The largest recognition for our research quality is the recent first positions of TU Delft in both the ranking by subject by the Center for World University Rankings (CWUR) and the Shanghai Ranking in the field of "Water Resources". Although more research groups contribute to this success, definitely the Water Management programme is pivotal, working on the basics of understanding the global water cycle and its application fields, such as urban water supply and storm water and wastewater management. Staff members are frequently invited as key-note speakers at (high-quality) international conferences and we see invitations for editorships as a mark of recognition, e.g. Prof. Medema for Water and Health, Prof. Savenije for Hydrology and Earth System Sciences, Prof. Rietveld for Drinking Water Engineering and Science and Jules van Lier for Water Science and Technology. Special emphasis is given to the acquirement of grants, extending the funding portfolio. This has led, among others, to five personal grants (2 NWO-Vidi, 1 NWO-Veni, 2 NWO-Aspasia), 4 STW-TKI projects, 3 NWO-WOTRO integrated projects, 2 DGI grants, 2 EU Marie Curie Joint Doctorate programmes, and 6 KIC EU projects.
In addition, Prof. Savenije was elected Fellow of the American Geophysical Union (AGU) (2014), awarded the Alexander von Humboldt medal by the European Geosciences Union (EGU; 2015), and inducted as Knight of the Order of the Netherlands Lion (2014). The prestigious Darcy medal of EGU was awarded to Prof. Van de Giesen (2015). Dr. Van Halem received the L'Oreal-UNESCO For Women in Science scholarship (2015). In addition, Prof. Van Lier and part-time Prof. Medema were awarded as International Water Association (IWA) fellow. The academic reputation and international position and recognition are also underscored by the number of internationally renowned visiting professors (J.J. McDonnell, M. Sivapalan, J. Lund, J.S. Selker, A. van Haandel).

Table 5. PhD candidates in the Water Management programme.

Starting year	Female	Male	Total	Grad.	Grad. <= 4 yr		Grad. <= 5 yr		Grad. <= 6 yr		Grad. <= 7 yr		Not yet finished		Discontinued	
2008	4	16	20	14	2	10%	9	45%	11	55%	13	65%	0	0%	6	30%
2009	7	15	22	15	1	5%	7	32%	15	68%	15	68%	5	23%	2	9%
2010	10	19	29	17	2	7%	8	28%	15	52%	17	59%	7	24%	5	17%
2011	9	22	31	18	8	26%	15	48%	18	58%	18	58%	12	39%	1	3%
2012	7	12	19	4	1	5%	4	21%	4	21%	4	21%	14	74%	1	5%
	37	84	121	68	14	12%	43	36%	63	52%	67	55%	38	31%	15	12%

Note: This table includes Standard PhD candidates (with employee status) and Contract PhD candidates (without employee status, receiving external funding) conducting research with the primary aim/obligation of graduating, based on a 0,8-1,0 FTE contract.Please note that the data in the dark cells is incomplete. There are still PhD candidates active from those starting years that are able to graduate within the timeframe of the given years. Reference date: 1 januari 2017

Dr. Van Halem received the L'Oreal-UNESCO For Women in Science scholarship.

1.4 Societal relevance

The societal relevance of understanding water availability, water use, water quality, treatment and transport is very clear. In particular, the research for developing countries that are more vulnerable to floods, droughts, water supply and sanitation gives the group a valuable international presence in addition to the involvement in the Netherlands. As

Prof Savenije receives Royal award.

Water for crops and for the city

Nick van de Giesen

Water for crops and water for urban areas. Those are the two global challenges that Professor Nick van de Giesen sees for water management. 'More and more people are moving to cities, and those cities need water, that much is clear. But what few people realise is that for every kilo of food, you need a thousand litres of water.'

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indicators for societal relevance the following topics were chosen: artefacts, instruments, datasets, etc.; internships and theses at non-academic institutes; projects in cooperation with societal group/industry; open-access publication; contribution to solving societal problems; and financing of chairs/research appointments.

The Water Management programme aims at disseminating the outcomes of the research by intensive collaboration programmes with e.g. water companies and the installation of part-time professorships, publishing in open-access journals and participating in popular scientific programmes and journals (e.g. University of the Netherlands, journal KIJK). In addition, the Water Management programme increased collaboration with other programmes (Transport Policy & Management) and institutes (UNESCO-IHE/UN-IHE) focussing on policy-making and societal constraints, where the Water Management programme itself concentrated on technology, monitoring and model development. This is illustrated by the acquisition of three NWO-WOTRO integrated projects (highly competitive research programme, combining technical science with social science) and combined education. In addition, within the international research initiative of the International Association of Hydrological Sciences "Panta Rhei", focussed on the interaction between water and society, initiatives have been developed to enhance the understanding of co-evolving human-water systems.

1.4.1 RESEARCH THEMES

Theme A: Observation & modelling of water resources

Robust, integrated modelling of catchment-scale hydrological response and water-quality dynamics is highly relevant to predict floods, droughts, groundwater recharge, land-atmosphere exchange and diffuse pollution within limited uncertainty. This is of critical importance for sustainable water resources planning and management to prevent or mitigate the risks related to these factors and to facilitate the development of suitable policies. In The Netherlands, we cooperate closely with Rijkswaterstaat, who is in the process of implementing the recent developments into their hydrological forecasting system.

Probabilistic model predictions form the basis for risk-based water management and design. They allow managers to make more robust decisions that take into account both existing knowledge and data and lack thereof. For example, in the Yellow River Delta, probabilistic predictions of future changes in water demand and supply were used to identify best management options to match supply and demand. Similarly, accounting for uncertainty in predicted longevity of reactive barriers for groundwater remediation leads to more robust barrier design. Finally, probabilistic reconstructions of paleo-climate and paleo-hydrological conditions provide unique insights into impacts of past and future climate change that cannot be deduced from much shorter historical data records. Collaborative work with the Canadian Forest Service on Vancouver Island has provided insight into climate-induced changes in streamflow and the resulting impact on river salmon populations, which are of ecological and economic importance.

Knowledge on evaporation will improve our hydrological models that are used to predict floods and droughts, especially, with the expected climate change. Understanding of the water behaviour in and underneath the vegetation canopy will help to improve weather forecasts, where uncertainties in the air water content are to a large extend responsible for wrong rainfall estimations. Knowledge of evaporation is also of direct use for farmers that need to irrigate their fields. Monitoring vegetation with radar is of significant interest to several companies in the Netherlands who develop products from remote sensing. A key challenge is separating the influences of soil moisture and vegetation (water) in the observations. Research activities monitoring major Dutch crops have been used by e.g. NEO bv and SuikerUnie, and have been included as part of the Precisie Landbouw 2.0 collaborative project.

Knowledge of the variation of the groundwater velocity is relevant for drinking water companies that rely on the subsurface to filter the water when it flows from a surface water body to a pumping well. Experiments at drinking water companies PWN, Waternet and Brabant Water are ongoing or planned. The ability to explain the measured variation of the groundwater head with an open-source computer programme is important for both direct prediction and for analysis of the measurements before use in a model. The ability to improve and automate time series analysis will make the best use of the many observation wells where groundwater heads are

Sustainable waste water purification

Merle de Kreuk

Waste water purification with granular sludge has proven very efficient. However, how suspended solids are removed from sewage and possibly broken down by granular sludge is unknown. Merle on this subject: 'I want to see and comprehend what bacteria do to the colloidal fraction and decomposable particles in granular systems, in (an)aerobic processes. I want to unravel the granules and their components - cells, polymers, enzymes. If fundamental research enables you to understand exactly what is going on, the opportunity exists that you may be able to devise different, smarter processes.'

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measured. Consulting firms (e.g. Witteveen en Bos) and water boards (e.g. Aa and Maas) have already expressed interest to contribute and/or apply this new code.

The 2012 paper "Socio-hydrology: A new science of people and water" defines a new area of research where society is seen as an integral part of hydrological theory, and emphasises that water is a key element of our socio-economic system and should be managed in a broad societal context. The emphasis has been on understanding the coupled nature of humans with their water environment. All studies were carried out with explicit questions addressing societal concerns such as how water can be valued and the competition for water between agriculture and the environment. The research contributed to Panta Rhei and attracted the attention of the United Nations World Water Assessment Programme in Perugia, Italy, leading for example to a contribution to the United Nations World Water Development Report of 2017 on recycling phosphorous from human and livestock-derived wastewater.

Particularly in developing countries, lack of water system understanding is one of the factors that hamper sustainable development of these resources. Remote sensing and citizen science contribute to system understanding, while citizen science can raise environmental awareness as well. The research is executed with partners from developing countries (Myanmar and Vietnam) and is leading to a direct increase in research and innovation capacity in these countries. Dutch companies including small medium enterprises and start-ups that develop novel monitoring techniques or information solutions are involved in the research to expose them to new markets.

Theme B: Water quality, treatment & reclamation
The recent demand to convert our current linear economic setting to a more circular one also impacts the (waste) water sector. Wastewater is increasingly regarded is a mix of non-defined resources, which require treatment technologies oriented to recovery of these resources rather than just eliminating them. Anaerobic treatment is an eminent example of this approach. Widening its application potential is supportive to the current societal needs. At present, as a consequence of our research, the company Biothane-Veolia has implemented over 10 full-scale AnMBR reactor systems (see above), whereas Paques is currently assessing the feasibility of this technology for chemical wastewaters. Approximately 10 million ton waste-activated sludge (WAS) is produced annually in Europe, while disposal costs have been estimated to be 50% of the total costs for sewage treatment. To lower these disposal costs, anaerobic digestion is used to reduce the amount of excess sludge and partially recover the biochemical energy stored in sludge, in the form of products like biogas and VFA. However, at present, anaerobic digestion removes only about 30-40% of the biomass' organics. In our research, we aim for higher conversion efficiencies, which will lead to increased product formation and decreased transport and disposal costs. Furthermore, the knowledge gained about product recovery can be translated to other waste streams, such as organic waste or wastewater with a high suspended solids content. To underline the societal relevance and interest for wastewater treatment in general, Merle de Kreuk was invited for the Universiteit van Nederland, aiming at a general public (over 4500 views in 2 months at YouTube), to give a 15-minutes presentation in the series "dangerous water" with the title "what happens if I flush the toilet".

Tailor-made ceramic membranes and adsorbents can contribute to water and resource recovery from wastewater. Evides Industriewater has tested the membranes coated by ALD and developed by our group in a pilot on raw sewage water. PWN-Technology will also start a pilot with these tailored membranes for the treatment of waste fluid of ion exchange resin. Coorstek participates in this research to be able to adapt their microfiltration ceramic membrane with ALD technology for treatment of oily waters.

One of the NWO-WOTRO funded projects addresses the reclamation of used urban water (sewage) for industrial and agricultural use in water scarce situations in Mozambique. The project team of 4 PhD students and 1 post-doc consists of both technological and sociological experts to address the problem in an integrated way. The project is supported by water companies, consultancy firms and universities in both the Netherlands and Mozambique. Through workshops and demonstration plants, the topic is now put on the political agenda, and frugal innovative solutions, based on the above technologies, can be tested.

In the Netherlands, drinking water companies have recently adopted a new guideline for arsenic (from 10 to 1 µg/L). This has resulted in the urgent demand for knowledge on As(III) behaviour during conventional treatment (aeration-filtration) as well as for the development of new technologies to remove arsenic. At present, we collaborate with Brabant Water, Vitens, Dunea and Pidpa (Belgium) in proof-of-concept pilot studies to apply our newly gained knowledge into practice (STW FixAs). We also collaborate with organisations, like UNICEF and universities in India, Bangladesh and Nicaragua, to assure local embedding of our findings (NWO WOTRO).
Water quality models are useful for supporting knowledge-based management of polluted rivers and aquifers. The groundwater and reactive transport models we developed were applied to contaminated field sites in Belgium and Italy, and were used to evaluate longevity of existing reactive barriers at these sites. This was a collaboration with VITO and Sapion Consulting (Belgium), among others, and resulted in a new set of guidelines for long-term performance assessment of permeable reactive barrier sites. In addition, aquifers are increasingly being used by society to store or retrieve thermal energy, for natural or stimulated treatment of groundwater pollution, and to temporarily store water to balance times of water abundance with water demand. However, it is essential that their impact on groundwater quality and other water consumers (e.g., drinking water companies) is understood to optimise their performance and limit their environmental impact. Research projects on Managed Aquifer Recharge (DeltaMAR and AGRIMAR) are conducted with various private companies incl. Acacia Water B.V. and Tauw B.V. who profit from and apply the generated knowledge in practise.

Theme C: Urban water systems
New algorithms for increasing self-cleaning capacity in drinking water distribution networks have been demonstrated to perform much better than designs that rely on heuristics and engineering insight only. These are being added as a package to a Python tool for hydraulic analysis, freely available to use for all. They have been successfully demonstrated on Dutch network models from Purmerend, and their use is envisaged to carry out real network reconfigurations for reducing discoloration risks in the Netherlands and the UK.
Leak detection is key to avoid water loss and water main collapse due to background leakage. Our approach significantly reduces the search area and is currently being tested and disseminated at a Dutch water company. Ongoing work on leakage reduction will also be relevant to very leaky systems in the water distribution systems of developing economies. The effect of intermittent drinking water supply on microbiological safety, leakage levels, the life of pipe infrastructure, and operational cost is severe. Such tools will make contributions towards efforts to meet Sustainable Development Goals on water and sanitation and are being developed in cooperation with the water company of Addis Ababa.

Urban flooding induced by extreme rainfall events can have disastrous consequences for urban communities. Ongoing urbanisation and densification in combination with impacts of climate change have increased urban flood risks worldwide. We work in close collaboration with city authorities, especially Dutch (Rotterdam, Amsterdam) and European cities (Paris, Leuven, Brussels, London, Birmingham) to support development of research outcomes towards practical implementation. Interest in the results of our research in society is evidenced by recurrent appearance in public media, including RTL4 News, BN Radio, Volkskrant, Parool, Trouw, New Scientist, Haagsche Courant, as well as appearances at public events such as the Water Republic, Let's Talk Water, Social Media Week Rotterdam, public lecture Science Centre Delft.

The research on transport of concentrated domestic slurries connects to the various initiatives in the Netherlands, in which novel sanitation systems are being studied at a large scale. The novel sanitation systems make use of low-diameter transport pipes (up to 50 mm) in which the toilet wastes are collected with vacuum sewer systems applying only 0.7 litres per flush. The collected so-called "black water" is combined with grinded kitchen waste (produced by household grinders) with the objective to recover bio-energy in the form of methane, thereby contributing, together with partners from society, to the wanted circular economy.

In general, the research on urban drainage is conducted in close cooperation with the sector, often in living labs. This enhances rapid uptake of ideas and results by the sector. RIONED, one of the funding organisations of the Urban Drainage programme, publishes frequently short descriptions of PhD students and their projects as part of their newsletter and on the website. Moreover, RIONED started a series of publications in which Dutch summaries of 25-30 pages are given of each PhD thesis being funded by the Urban Drainage programme, enabling rapid uptake by the sector of developed knowledge.

Table 6: Overview of industries and organisations that participate in projects of the Water Management programme.

Company	Project
Evides	Innovations in industry water cycle
Oasen	Innovations in drinking water supply
Waternet / Vitens / Brabant Water / Oasen / PWN	Sprinklers in in-house installations
Veolia Biothane	Anaerobic MBRs for wastewater treatment
Shell	Pearl G T L salt and brine stream purification
Tauw	SKINT
Deltares	Storm water discharge
Arcadis/RHDHV/GMB Grontmij/TAUW/ Waternet/ Evides/ Witteveen+Bos/ VanderValk+DeGroot/	Knowledge programme Urban Drainage
KWR	Development of NHI
STOWA	Sludge quality in MBR
VEWIN	Organic micros in drinking water
Bosman Watermanagement	OZONEW
Waternet/KWR	Sewermining: energy and water recovery from sewage
Vitens	Innovative treatment technologies
HKV Lijn in water bv/ Deltares	Real-time control of water systems
Paques	Highly saline phenolic wastewaters
Waternet/PWN/Oasen	Dutch drinking water benchmark
Rossmark/Evides	Tomatoes on sewage
Waternet	TAPES
Layne Hydro/ WHPA inc.	Analytic element models for water control
Deltares	Observing urban climate systems
TTI	New reactor concepts
Rioned	Urban Drainage International
RHDHV/Vitens/Waternet	Filterexpert

Theme D: Monitoring & control of water processes
Better understanding of the availability of water over time and space is extremely important in a world that needs to double its food production by 2060, while reducing the total amount of water diverted for irrigation. The societal relevance is probably most acute in the Global South, which is why many of our projects are located in Asia and Africa. The TAHMO project is a clear example that combines better insights into climate and climate change, with financial sustainability and education. The start of TAHMO has mainly been financed through donors, such as USAID, Rockefeller, and the Dutch government. Recently, we have received an investment of one million dollars from IBM, clearly exemplifying the broader societal interest in TAHMO.
Large reservoirs bring benefits to people in the form of flood control, water for irrigation and electricity products. However, dams can also have adverse side effects on downstream ecosystems. With more optimal operation of dams floods can be reduced, energy and agricultural production can be maximised, navigation can be enabled and environmental damage minimised. Our research is executed in close cooperation with the Irrigation Department of Myanmar that is responsible for a large part of the reservoir operation in that country and planning to use the developed algorithms.

Monitoring and control research in the drinking water supply is relevant since water supply companies deal with loss of experienced operators and engi-

neering and increased automation of the processes. The developed models and simulators are now being implemented in tools of consultancy firms (Aquasuite of RHDHV) and in programmes for the improvement of operations in water companies (SLIMM at Vitens). Water-demand prediction models (OPIR) are implemented at two-third of the water treatment plants in the Netherlands and are also being exported. The demand models support improving the water quality of the drinking water, diminishing the costs for production and distribution and must finally decrease the impact of large bursts through rapid identification and action. In the control of district metered areas in a UK water network, the modelling and control resulted in a 7% reduction in leakage.

1.4.2 USE

We suggest to assess the use of research projects in terms of participation of societal organisations, publications in open-access journals and contributions to solving societal problems.

A list with societal organisations that participate in our projects is provided and it is clear that end-users, consultants firms, suppliers and research institutes are involved (representing the so-called Golden Triangle). Open-access journals make it possible for non-academic partners to read the products of our research without extra payment. Our programme is one of the front-runners in open-access publication and we heavily support the initiative of conventional journals to revert to open access. We are closely involved in the following open-access journals: Hydrology and Earth System Sciences (HESS), Drinking Water Engineering Science (DWES), and IWA Publishing. We stimulate our researchers to share their publications and data.

1.4.3 RECOGNITION

Water Management had six part-time professors who maintain the link to the water sector, including the societal aspects. These professors are externally funded and part of strategic MoUs with the societal partners (water companies, research institutes).
In addition, full-time staff members are/were represented in national committees with societal impacts, such as "Top Sector Water", "Visitation committee Water", STOWA and KWR.
Finally, as mark of recognition of the work of the programme on societal relevance, research of several staff members has been highlighted in national media (e.g. Volkskrant, NPO 1) and they are often called on to comment on nationally relevant developments in the water sector.

1.5 Viability

In observation & modelling of water resources, the major challenges are to predict floods and droughts. We have made great progress in the last years, but especially the eWaterCycle project and our research into evaporation monitoring show great promise to contribute to such predictions. Water quality, treatment & reclamation will mainly focus on the removal of emerging contaminants, recovery of energy, water and other valuable compounds, being important for safe drinking water, combating water scarcity and environmental pollution, and contributing to a circular economy. The EU project Zerobrine and NWO-funded projects LOTUS, AdOX and Deltap are examples of the impact the programme can make in the coming period. Urban water systems will be affected by accelerated degradation, because of their age. Huge investment programmes are expected in the sector and therefore innovative, efficient systems should be investigated and developed to prepare for the future. The TU Delft marked this area as a priority and, next to the existing Urban Drainage programme and NWO-TISCA projects, in cooperation with the entire Faculty of Civil Engineering and Geosciences, and societal partners extra research capacity will be mobilised, including one full and two assistant/associate professors in 2018. The water sector will furthermore rapidly invest in innovative smart water solutions, including monitoring & control of water processes. Together with the water sector, these challenges will be tackled through a more application-driven approach, e.g. by already formulated PDEng projects.

Since the last research assessment, the balanced funding strategy is further improved by giving more attention to grants from research entities (NWO) and EU projects (see above). This has resulted in a healthy, even distribution between second and third money streams. Especially, the attraction of the large number of personal grants and NWO grants, attracted by relatively young staff members can be seen as a sign of viability.

Further, much attention is given to the recruitment of new, high-potential full-time staff members (seven tenure-track positions), striving towards gender equity (within budgetary limitations), expanding the research (and education) capacity. The programme also benefitted from the new internal TU Delft regulations to appoint associate professors as full professor when quality permits. Therefore, in 2017, the programme was strengthened with two, young female full-time professors.
Because of the growth in research and education the programme has faced, a healthy financial situation is created, giving the opportunity to continue the staff development, also in case of personnel turnover. Focus is given on quality and development perspective, rather than only achieved performances.

The various research groups in the programme have worked closely together increasing the critical mass and to divide educational and administrative tasks evenly, avoiding overlaps, improving integration and diminishing the vulnerability of the groups. This has also resulted in the establishment of a new Master's educational track on Environmental Engineering with, after 1 year, an inflow of 40 students, next to the established track Water Management with about 70 students/year. These educational tasks stimulate cooperation and research ideas, and attract young academics from all over the world. The cooperation in research goes beyond the borders of the programme. Within the Faculty of Civil Engineering and

SWOT of the Water Management programme.

Strengths	Weaknesses
• Water Management has a balanced portfolio between scientific excellence and application into practice. This is evidenced by the grants, awards and spin-offs. In addition, funding is well spread with great opportunities to co-operate with market and societal organisations, while water is a spearhead in Dutch policy. • The programme is growing with young talented staff members, leading to more individual grants, where special attention to gender equity is given. The output per staff member is relatively high. • Research is well connected to education with great international exposure through on-line courses (including MOOCs and the entire Master's programme in Water Management). • The research environment is open and collaborative and based on mutual respect.	• Although large research funding is acquired, only a few full-time, tenured researchers on the topic "subsurface water infrastructure" are present, making the programme highly dependent on part-time, externally hired staff, and hampering intensive cooperation with other programmes (e.g. Geoscience and Engineering). • In relation to other research institutes, public relations of the programme could be better, in order to better demonstrate the outcomes of research and education to the outside world. • Internal visibility of the programme in the undergraduate course Civil Engineering is too low, since this course is highly focussed on construction, making the programme highly dependent on 'external' students.
Opportunities	**Threats**
• Even stronger co-operation with research institutes such as Deltares and KWR to acquire research funds from EU, also making use of the perspective of the recruitment of new staff on Urban Water Infrastructure. • Expanding the new MSc track on Environmental Engineering to a full programme, increasing exposure and attracting more highly talented students. • Using alumni working in industry for our educational programmes and to set up innovative research with a strong utilisation paragraph.	• The number of PhD students per staff member is relatively high, possibly leading (in connection to education) to overloading our personnel. • Changes in the national funding schemes and internal fund-allocation schemes can influence the long term development of the programme.

Drinking water quality after Thermal Energy Recovery

Jawairia Imtiaz Ahmad

Water companies are keen to use cold from drinking water as a source of energy for cooling purposes, such as cooling houses. This technique, called Thermal Energy Recovery, companies wish to operate climate friendly and turn water distribution networks into a renewable energy resource. But if the drinking water loses its chill, will it still be fit for human consumption? And what about the microbiological quality of the water? That is what PhD candidate Jawairia Imtiaz Ahmad is trying to find out at TU Delft's Waterlab.

www.tudelft.nl/en/ceg/research/stories-of-science/drinking-water-quality-after-thermal-energy-recovery/

Geosciences, strong relations with for example the Geoscience and Remote Sensing programme exist on urban and rural hydrology, and with the Hydraulic Engineering programme on water resilience. Water Management is constantly improving its research and education, looking for new initiatives. One example is the leading role in online education. Thousands of people around the world participate in the Water Module (MOOC Water & Climate, Urban Sewage Treatment, Drinking Water Treatment). Therefore, the research programme is viable in terms of funding, staff and impact.

1.5.1 BENCHMARK: IMPERIAL COLLEGE

In order to benchmark our section, we visited the Civil and Environmental Engineering Department of Imperial College (UK). This department is subdivided into sections. We spoke with the head of the sections of Fluid Mechanics and Environmental and Water Resources. The sections are typically smaller than our departments/programmes with about 8-12 FTE of permanent staff members. The staff members are recruited internationally with the emphasis on scientific quality, where every attempt is made to avoid "unconscious bias". Like the Water Management programme, the staff members are basically treated as PIs and have the opportunity to grow from lecturer, via senior lecturer, reader to full professor. Another similarity with the Water Management programme is that the PIs are responsible for funding of PhD students and that connections with industry are stimulated, also to attract co-funding for research.

Like in the Water Management programme, PhD students are typically funded through individual projects, large managed programmes, or self-funded. The projects are typically co-funded for 50% by industry and the quality of the potential PhD student is the most important selection criterion. The length of the PhD trajectory is typically shorter than at TU Delft, about 3-3.5 years, occasionally preceded by 1 year of Master courses and projects. As is the case at TU Delft, the PhD students at Imperial College are monitored by a College-wide Graduate School that includes doctoral education. Attracting talented PhD students appears more challenging than getting research funding.

Similar to that of the Water Management programme, the publication strategy of the individual staff members concentrates on high-quality papers in top journals (such as Water Research, Hydrological Processes, and BioResource Technology) rather than a high quantity of papers. The logical consequence of this strategy is that the papers are well cited, which results in higher h-indexes, invited keynote speeches, etc.

The societal relevance is just as important to the Imperial College researchers as it is to ours. Therefore, funding for PhD research (and EngD education) should come for about 50% from industry. In addition, there are several visiting professors (from industry, often retired) that lecture at the sections to stimulate interaction. The availability of laboratory facilities is also seen as an important asset supporting impactful research.

1.5.2 STRATEGY FOR THE FUTURE

In the upcoming period, the research programme on Water Management will further build on its major strengths (e.g. scientific excellence, link to practice and education, and individual development). At the same time, it will address its most pertinent shortcomings, e.g. development of new area in urban water infrastructures, and diminishing overloading staff by recruiting five new, extra, scientific staff members in the coming year. We were successful in the previous period in attracting external funding via FP7, Interreg and through NWO-Veni/Vidi/Aspasia. We will continue this strategy and see also many opportunities for new funding through EU by aligning with other research institutes in the Netherlands (Deltares, KWR), also by establishing joint appointments. Furthermore, we will continue and broaden the direct co-operation with industry focussing on specific topics of mutual interest (e.g. Nereda with RHDHV and arsenic removal with Vitens). The newly developed Master's track in Environmental Engineering will give extra exposure to students and industry, leading to an increasing number of graduate MSc students and increased impact in society. This strategy was also compared to the programme of Environmental and Water Resource Engineering of Imperial College (partner in a Bench Mark). What we learned is that focussing on quality (both in papers and people) is the right strategy and that the spreading of funding indeed increases the viability of the programme.

Structural Engineering programme

1 Research area and objectives

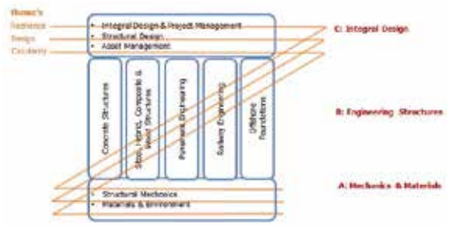
1.1 Background

Safe, structurally resilient, sustainable and functional buildings and infrastructure are key pillars for the prosperous development of our societies. Challenges differ from region to region, and new challenges lie ahead:

- Developing countries face huge investments to create sufficient buildings and infrastructure to support their growing population and economic activity;
- Developed countries not only face adaptation of buildings and infrastructure to demographic and climate changes, but also face enormous efforts to maintain and replace existing infrastructure.

Generally speaking, there is growing concern about the resilience of buildings and infrastructure to increased loading, natural hazards, antagonistic threats, already resulting in a growing number of failures and disasters. Furthermore, sustainability has become a key aspect of new developments. The construction sector accounts for 6% of global GDP and is responsible for 25-40% of the world's CO_2 emission. Another factor driving developments in the construction sector is costs. Costs are a key element in investment decisions for creating new or updating existing infrastructure and buildings. Both on a national and European level, ambitions are to drastically improve resilience, to reduce 50% of raw material use and become fully circular in 2050, and increase productivity with 10% combining quality improvement and cost reduction.

Figure 1: Clustering and coherence of research groups. The mechanics and material disciplines (cluster A) are linked tot the integral design disciplines (cluster C) through the engineering structures disciplines (cluster B). All discipline groups gear their research to the three strategic themes; resilience, integral design and circularity.



Meeting today's and future challenges requires:

- A clear focus on the central themes for materials and structures: resilience, design (including sustainability) and circularity of materials and structures;
- Integration of research on different levels: materials, engineering structures and integral design. The Structural Engineering programme combines the expertise areas needed in a cluster of connected groups (see Fig. 1).

As the construction sector, given the huge financial and societal impact of failing structures, is conservative and hesitant in introducing innovations, it is imperative that new models arising from scientific research are validated with experiments on a scale reflecting full-scale applications. The Structural Engineering programme has access to both excellent modelling tools and experimental facilities.

1.2 Mission and ambition

The mission of the Structural Engineering programme is to contribute to solving societal challenges in the building and infrastructure sectors, by

- realising top-level fundamental and application-inspired research, supported by excellent and unique experimental and numerical facilities, and
- creating an open and stimulating environment for young researchers to develop their full potential.

ASSESSMENT 2005-2010

In the previous assessment of 2005-2010 the Structural Engineering programme's scientific quality was ranked as very good, productivity was good but could be higher, especially in terms of number of PhD theses, societal relevance was very good, but viability was ranked as moderate/good since six professors were about to retire and no clear plans were presented to approach the future, while the financial health was marked as insufficient. Specific recommendations from the previous assessment committee to the programme were:

1 Succession master plan with diversity;
2 Reinstall integral design;
3 Reconsider the group and chair division;
4 Larger groups with broader focus;
5 Stronger coherence and cooperation;
6 Emphasis on PhD training and success rates.

Strategy 2010-2016

Main focus points in the strategy of the past six years were improving financial soundness, developing a more balanced combination of disciplines attuned to research questions from outside partners, strengthening experimental facilities and improving viability and diversity. Examples of actions are:

- Staff was reduced with 33 fte, of which 19 fte scientific staff.
- The programme consulted on- and got full support for the renewed research plans of major national stakeholders like Rijkswaterstaat, ProRail, major contractors, engineering firms and suppliers. Discipline groups on integral design and railway structures were reinstalled and revitalized, new appointments of staff also supported revitalization of road and pavement engineering, and cooperation with Architecture was strengthened.
- The experimental facilities were revitalized by both managerial actions (clearer responsibilities of discipline groups) and investments (enabled by allocation of additional funding of the Executive Board of the University). Furthermore, the facilities were opened to groups with mainly computational and theoretical focus (e.g. pavement mechanics and masonry mechanics). This resulted in addition of valuable new facilities and a closer connection between theoretical developments and experiments.
- Eight new professors were appointed, half of which combine their appointment with outside functions at other departments or sectoral partners. 12 assistant professors were appointed in tenure tracks, spread evenly over de discipline groups. Diversity was improved in the balance of national and interantio al influx and also in the sense of in-house disciplines; new appointments not only had background in civil engineering, nut also in physics, biology, electrochemistry and policy, design and management. Gender balance has improved on PhD, postdoc and junior staff level, but remains a point of attention at higher staff levels.

The ambition of the Structural Engineering programme is to be recognised as the worldwide leading research group in the field of invention, design and implementation in engineering practice of smart, resilient and reusable, materials, structures and infrastructure.

1.3 Strategy for the next 5 years

The main strategic actions for the next 5 years are:

- Gearing the programme to the three themes: resilience, design and circularity of materials and structures;
- Using staff mutations to further rejuvenate the group and adapt the research portfolio;
- Developing large multi-disciplinary projects in cooperation of the research groups in the programme;
- Creating a better balance of fundamental and applied science in projects.

1.4 Objectives for the next 5 years

Organisational:

- Maintain and further improve viability and diversity on personnel level: timely anticipating on retirements and vacancies and further rejuvenating staff and expertise (continuing the earlier shift from influx of full professors to development of young assistant and associate professors in postdoc and tenure tracks; permitting PI and pyramid models in groups);
- Further strengthen multidisciplinary cooperation financed through new long-term integrated programmes, similar to the present NWO-TTW Perspective programme EUROS and the IS2C, TISCA and NGInfra and DIMI initiatives.

Scientific quality and societal impact:

- Further improve publication rates in high-quality scientific and professional journals higher impact factors;
- Stimulate faster adaptation and utilisation of innovative (renewable) materials, software patents, design codes and other products developed both on a national and international level;
- Develop a 'Deltaplan for Infrastructure' with major stakeholders as ProRail, Havenbedrijf Rotterdam, provinces and Rijkswaterstaat and attracting funding for this plan through a mix of second and third-stream financing;
- Actively participate in the energy transition by inventing and implementing new materials and structures for wind and ocean energy; play a key role in the national programme GROW (> M€100) and European initiatives focusing on the energy transition.

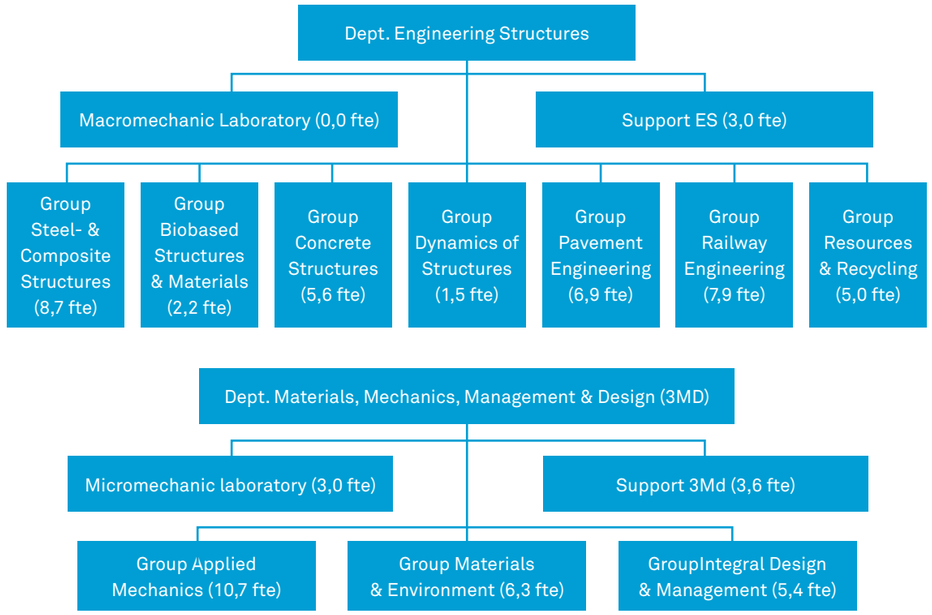
Educational:

- Maintain a strong contribution to MSc programmes in Structural Engineering, Building Engineering, Construction Management & Engineering and Offshore Engineering;
- Improve PhD success rate, and actively involve MSc students, PhD students, postdocs and staff in development of multidisciplinary research projects with outside partners;
- Provide lifetime learning via professional education (ProfEd) and online education.

Research:

- Maintain a leading position in developing new materials and innovative reuse of the existing ones;
- Maintain a leading position in computational modelling of materials and structures with the focus on physically sound multi-scale and multi-disciplinary modelling of fracture, contact and dynamic interaction;
- Play a key role in the development of modern road and railway infrastructure using new resilient and reusable materials;

Figure 2: Organigram of the two subdepartments of the Structural Engineering programme.



Research staff 2011-2016 in the Structural Engineering programme.

Structural Engineering	2011		2012		2013		2014		2015		2016	
	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE	#	FTE
Scientific staff (1)	52	18,6	53	17,8	56	17,4	56	17,8	59	17,7	59	18,9
Researchers (2)	50	17,1	45	18,9	50	22,2	73	31,4	94	42,9	122	52,1
PhD candidates (3)	136	80,1	138	87,7	134	92,5	139	91,8	146	94,1	139	89,4
Total Research staff	238	115,9	236	124,3	240	132,2	268	141,0	299	154,7	320	160,4
Support staff	16	9,0	17	9,1	16	9,2	17	9,4	19	10,6	20	12,1
Total staff	254	124,9	253	133,4	256	141,4	285	150,4	318	165,4	340	172,4

(1) comparable with WOPI category HGL (full professor), UHD (associate professor), UD (assistant professor), tenured and non-tenured
(2) includes post-docs and temporary 'onderzoekers'
(3) includes all PhD categories

- Develop new production technologies, enabling the use of new materials;
- Create a solid scientific base for project management and integral design disciplines.

1.5 Organisation of research

The size of one Department of Structural Engineering, covering the programme as a whole, is considered limiting to the management of the internal processes and social cohesion. Therefore, it was decided to split the current department into two sub-departments, each with their own management. The two sub-departments (see Fig. 2) share responsibility for the educational programmes, gearing research to the three strategic themes (resilience, design and circularity) and joint acquisition of large multi-disciplinary projects.

	Theme		
Chair	Resilience of materials & structures	Design of materials & structures	Circularity of materials & structures
Computational Mechanics	●		
Structural Mechanics	●	●	
Dynamics of Solids and Structures	●	●	
Concrete Modelling & Material Behaviour	●	●	●
Experimental Mechanics	●	●	●
Durability	●		●
Sustainability	●		●
Resources & Recycling			●
Steel, Hybrid and Composite Structures	●	●	●
Concrete Structures	●	●	●
Timber Structures		●	●
Structural Design / Buildings		●	
Construction Technology of Civil Engineering Structures	●	●	
Pavement Engineering	●	●	●
Pavement Engineering Practice	●	●	●
Railway Engineering	●	●	
Rail Systems & Monitoring	●	●	
Integral Design & Management		●	
Engineering Asset Management	●	●	●
Project Management		●	

● main topic / ● major topic

Scientists will be appointed in each of the themes listed in the above table to take the lead in organising regular meetings with fellow scientists of the relevant groups of both sub-departments for:
- Knowledge exchange;
- Identification of funding opportunities;
- Stakeholder analysis;
- Joint project development.

Personnel
Since the previous assessment, viability in terms of long-term staff development has vastly improved (see table Research Staff on page 98). After retirements and replacements, tenured staff has stabilised at a level of about 18 fte. The population of PhD students stabilised around 90 fte, 23% is on the staff payroll, 77% receives a scholarship, is directly funded by industry or bring in their own money (per December 2016). 12 assistant professors have been appointed, in the tenure-track system for new academic staff, introduced by the TU Delft in 2012. Other research staff, mainly temporary postdocs and young temporary contract researchers, has increased from 20 to more than 40 fte, spread over all research groups. Overall this has led to a rejuvenation of the researchers' population, and a stimulating environment for young researchers.

The outlook for the next 5 years is that of stable to slightly growing staff numbers. Goals, connected to the strategic personnel plan, are to firmer integrate the design disciplines with the groups working on the development of new materials and structures, and enlarge and focus research power in the field of energy transition. Scouting for external young talent will be continued.

Research Facilities
Research of the Structural Engineering program combines modelling development with experimental validation. The laboratory facilities, both experimental and numerical, of the Structural Engineering programme are seen as a strategic asset, giving the it a unique position in the scientific community and for its stakeholders.

Experimental testing is carried out at multiple scales:
- Micro-scale (Microlab and Pavement Engineering laboratory): for research on materials;
- Macro-scale (Macrolab): for large-scale testing and validation of structural behaviour of innovative structures and their components and to validate upscaling of new materials and test the (load bearing) capacity of existing infrastructure;
- Field scale (LinTrack pavement testing facilities, CTO measurement train): for tests of pavements, rail systems and transitional structures, steel bridges and on site proof loading of existing structures to investigate their capacity.

Capabilities are further enhanced by the development of monitoring techniques (e.g. acoustic emission for concrete structures, fiber-Bragg-grating for pavements) for the increasing importance of structural health monitoring.

The outlook for the next 5 years is large-scale maintenance, replacement and upgrading of the facilities. An integral investment planning is in preparation. Computational facilities consist of excellent computational software, i.e. multiple non-linear FEM packages, parametric design software, BIM systems etc., and a multi-core cluster machine, computer infrastructure required for the development and use of this kind of software.
The outlook for the next 5 years is to incrementally upgrade the Linux cluster machine of Structural Mechanics and initiating the setup of a (>15,000 cores and low cost data storage) high-performance computing facility in the broader context of the Delft Centre for Computational Science and Engineering (DCSE).

Funding
As already explained, actions (staff reductions) were taken in 2010 to turn around the negative financial position of the programme. Unfortunately, in 2012, first-stream funding reductions hit the programme, creating new challenges. The funding situation steadily improved since then by a combination of increased BSc, MSc and PhD output and success in increasing the volume of contract research and grants. The outlook for the next 5 years is positive; the base financing (1st money stream) is expected to remain stable, the variable funding (PhDs and students) is expected to slightly increase. This provides a firm basis for long-term funding.

Overview of the funding and expenditures of the Structural Engineering programme.

Structural Engineering	2011		2012		2013		2014		2015		2016	
Funding:												
Direct funding (1)	6.095	46%	5.349	40%	5.899	43%	6.489	42%	7.270	43%	8.618	50%
Research grants (2)	541	4%	1.505	11%	1.927	14%	1.691	11%	1.680	10%	883	5%
Contract research (3)	6.357	48%	6.604	49%	5.955	43%	6.822	45%	7.799	46%	7.875	45%
Other (4)	309	2%	-14	0%	30	0%	320	2%	42	0%	-50	0%
Total funding	13.302	100%	13.444	100%	13.811	100%	15.322	100%	16.791	100%	17.326	100%
Expenditure:												
Personnel costs	10.242	76%	10.104	74%	10.252	71%	11.839	73%	13.124	79%	13.180	77%
Other costs	3.226	24%	3.576	26%	4.132	29%	4.323	27%	3.457	21%	3.856	23%
Total Expenditure	13.468	100%	13.680	100%	14.384	100%	16.161	100%	16.581	100%	17.036	100%

Note 1: Direct funding (basic funding / lump-sum budget)
Note 2: Research grants obtained in national scientific competition (e.g. grants from NWO and the Royal Academy)
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

Furthermore, as the economic crisis is passing, the opportunities to attract contract research are growing. A clear goal is to actively seek long-term funding for large programmes from other sources as well (NWO, EU, etc.)

For good coverage of the expenditure, maintaining the funding through 2nd and 3rd money stream at the present high level is essential. Large deviations (upward and downward) in these money streams are a potential risk and preventing large deviations puts pressure on the organisation.

2 Scientific quality

In this paragraph and the following, evaluation aspects will first be discusses on the level of the programme as a whole, followed by a detailed description at the level of its main clusters (mechanics & materials, engineering structures and integral design).

Scientific visibility	
Type of recognition	**Quantity**
Scientists with h-index of 25 or higher	4
Personal grants (NWO, ERC)	2
Collective grants (NWO, H2020, AMI, RWS, NAM)	>15
International awards	22
National awards	3
Editors in chief	5
Membership editorial boards	24
Participation in international research assessment panels	4

The table above gives an overview of different types of external recognition of the scientific quality of the programme; details are given in annex 1. A list of relevant scientific performance indicators for the programme is given in § 3.1.2.

Main categories of research output for the Structural Engineering programme.

Structural Engineering	2011	2012	2013	2014	2015	2016
Refereed articles	92	130	125	119	114	184
Non-refereed articles (1)	7	0	1	0	2	2
Books	1	1	4	3	0	1
Book chapters	9	7	13	13	12	3
PhD theses	16	13	18	11	22	14
Conference papers	159	189	181	178	133	152
Professional publications (2)	33	56	32	32	22	27
Other research output (3)	39	44	133	61	111	64
Total publications	356	440	507	417	416	447

Note 1: Articles in journals that are non-refereed, yet deemed important for the field
Note 2: Publications aimed at professionals in the public and private sector (professionele publicaties), including patents and annotations (e.g. law)
Note 3: Other types of research output, such as patents, book reviews, editorships of books, editorships of journals, inaugural lectures, abstracts, designs / prototypes, appearances on radio or television, "populariserende artikelen" and other research output (internal reports, lectures)

2.1 Structural Engineering programme

Output
Productivity of the programme grew over the period 2011-2016. A particularly positive result is the significant growth of the number of refereed journal publications.

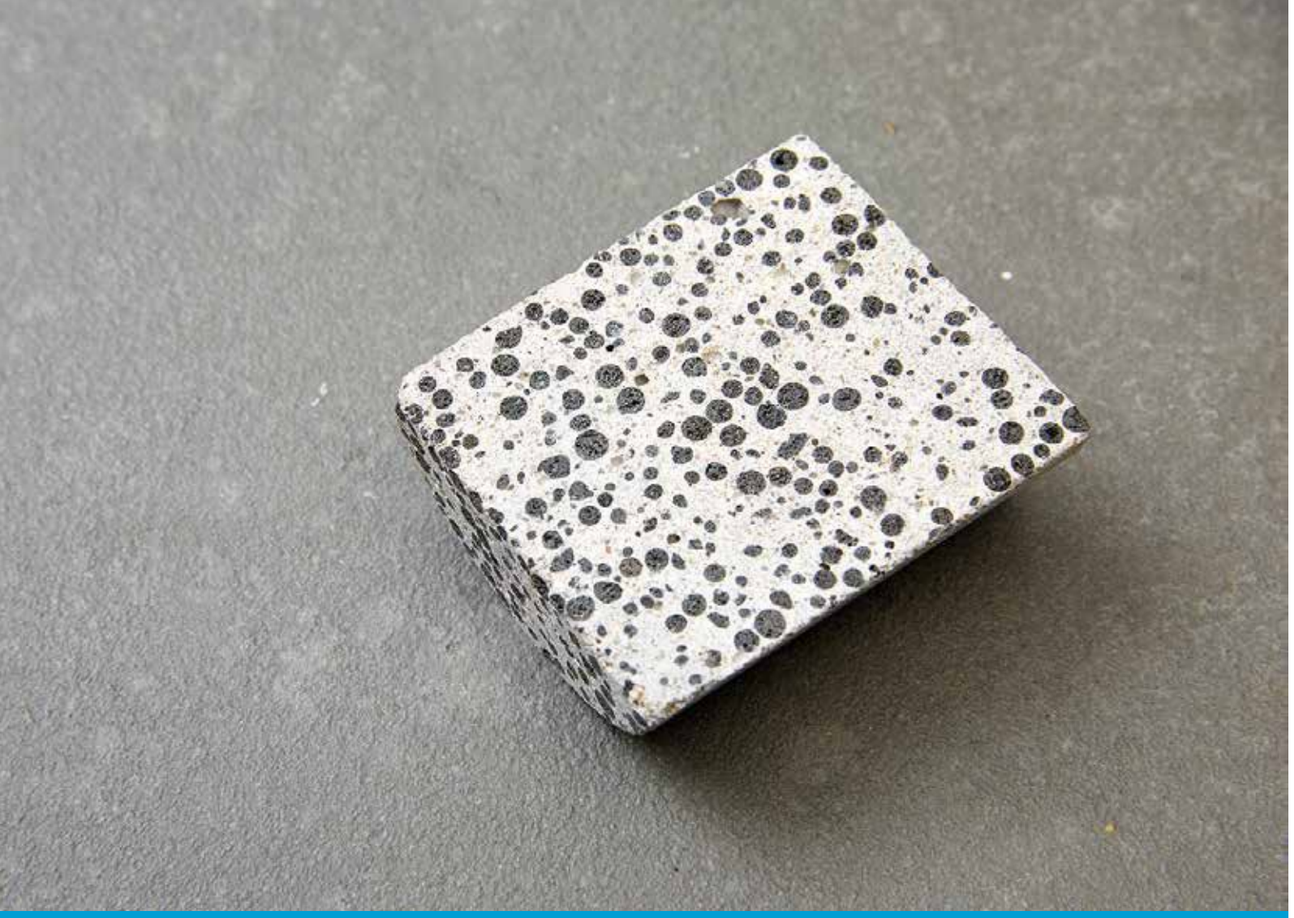
PhD candidates
The influx of PhD students has increased significantly. PhD students are all financed from external sources (national science foundation NWO, EU, industry, scholarships) for a period of four years. The central TU Delft ambition is a 70% PhD graduation rate in 2020. The present overall rate is 45% for the university as a whole, with the Structural Engineering programme at a level of 21% (with a dropout rate of 18%). In a discussion in the board of the Structural Engineering programme, three measures have been proposed:

- a more strict selection procedure with on-line presentations and small exercises;
- a realistic planning in the first year with involvement of the PhD student demonstrating the necessary competences, resulting in a fair go/no-go assessment after one year;
- an early start with writing and producing journal

PhD Candidates Structural Engineering.

Starting year	Female	Male	Total	Grad.	Grad. <= 4 yr		Grad. <= 5 yr		Grad. <= 6 yr		Grad. <= 7 yr		Not yet finished		Discontinued	
2008	6	15	21	15	1	5%	9	43%	14	67%	15	71%	0	0%	6	29%
2009	7	12	19	13	1	5%	3	16%	12	63%	13	68%	1	5%	5	26%
2010	5	23	28	13	0	0%	6	21%	13	46%	13	46%	10	36%	5	18%
2011	9	22	31	8	0	0%	6	19%	8	26%	8	26%	17	55%	6	19%
2012	1	20	21	2	0	0%	5	24%	2	10%	2	10%	16	76%	3	14%
	28	92	120	51	2	2%	29	24%	49	41%	51	43%	44	37%	25	21%

Note: This table includes Standard PhD candidates (with employee status) and Contract PhD candidates (without employee status, receiving external funding) conducting research with the primary aim/obligation of graduating, based on a 0,8-1,0 FTE contract. Please note that the data in the dark cells is incomplete. There are still PhD candidates active from those starting years that are able to graduate within the timeframe of the given years. Reference date: 1 januari 2017



Selfhealing concrete

Henk Jonker

Repairing cracks in concrete structures is a time consuming, costly but necessary business. TU Delft is researching how the self-healing capacity of concrete structures can be improved by using calcite-precipitating bacteria and what conditions are necessary for these bacteria to thrive.

www.tudelft.nl/en/ceg/research/stories-of-science/self-healing-of-concrete-by-bacterial-mineral-precipitation/

papers (the first journal paper should be finished after two years at the latest), reducing the amount of work to complete the thesis after four years.

Structural Engineering goals for scientific quality
Central goals with respect to scientific quality are:

- Improving citation rates further;
- Creating a balanced mix of experienced researchers and young high potentials;
- Creating an environment where young researchers, supported by experienced researchers, can develop to their full potential;
- Stimulating development of multidisciplinary projects and programmes through cooperation of the programme's groups on all levels;
- Further reinforcing strategic research subjects.

2.2 Research clusters

2.2.1 CLUSTER MECHANICS & MATERIALS

Materials and Environment
(Prof.dr.ir. E Schlangen, Prof.dr.ir K. van Breugel, Prof.dr. P.C. Rem, Prof.dr. R Polder)
The research focus of the group is chemical, physical and mechanical properties of materials with potential use in architectural and civil engineering applications, combining numerical modelling with experimental testing. The group works on five research lines with the materials cycle as connecting theme. These are:

- Sustainability, with focus on the use of sustainable concepts, a circular society and application of bio-based building materials;
- Durability, with focus on durability mechanisms, development of techniques for damage assessment and repair strategies;
- Experimental micromechanics, with focus on the development of experimental techniques for measuring properties of materials and development of new materials like self-healing, self-sensing materials and adaptive manufacturing;
- Materials behaviour and modelling, with focus on studying hydration mechanisms, structure formation and transport properties in cement-based materials and materials based on alternative binder systems;
- Resources & recycling, with focus on the development of separation technologies for waste streams and upgrading waste materials to useful building materials.

Structural Mechanics
(Prof.dr.ir. L.J. Sluys, Prof.dr.ir. J. Rots, Prof.dr. A.V. Metrikine)
The research focus of the group is the analysis of solids and structures relevant to civil engineering applications, supported by the development of mechanics based tools using novel computational and analytical techniques. There is a specific interest in new and innovative civil engineering structures and high-performance materials. The research work is fundamental and applied in nature, and has a mono, multi or trans-disciplinary character. Three research lines can be distinguished within the group:

- Computational modelling: nonlinear and sequentially linear finite-element modeling of structures, damage and near collapse states, including safety formats. Main application areas are masonry structures subjected to settlements and Groningen induced earthquakes, including multi-scale lab testing, and quasi-brittle concrete structures;
- Computational mechanics: with emphasis on the computational design of novel civil engineering materials through virtual materials testing, advanced multi-scale modelling techniques, and extreme loading analyses (e.g. variable amplitude fatigue, impact and blast loading);
- Structural dynamics: with emphasis on the dynamics of structures in interaction with various media such as ice, soil and water; both structural vibrations and waves are addressed, as well as the acoustic fields generated thereby. The main application areas are offshore, arctic and railway engineering.

Cooperation of the cluster Mechanics & Materials with other departments
The groups of the cluster Mechanics & Materials have strong cooperative ties to other TU Delft research groups such as the 3mE Department of Material Science & Engineering, Hydraulic Engineering programme of CEG, several groups at the Faculty of Aerospace Engineering and groups at the Faculty of Electrical Engineering, Mathematics and Computer Science.

Key publications cluster Mechanics & Materials

- Hendrikse, H. and Metrikine, A.V.(2015), Interpretation and prediction of ice induced vibrations based on contact area variation. International Journal of Solids and Structures, 75-76, p.336-348.

Testing the Rails

Zili Li

Four times a second, a mini railway wheel races over the mini railway in the basement of the building housing the Faculty of Civil Engineering and Geosciences. During the tests, wear on the wheels is measured down to the micrometre. The threedimensional acceleration measured in the bearings corresponds to the measurements conducted by the TU Delft 'measurement train' – a reallife carriage that travels on the Dutch railway network. The laboratory situation and reality are therefore comparable.

www.tudelft.nl/en/ceg/research/stories-of-science

- Meer, F.P. van der, Sluys, L.J., Hallett, S.R. and Wisnom, M.R. (2012), Computational modeling of complex failure mechanisms in laminates. Journal of Composite Materials, 46(5), p.603-623.
- Ma, Y., Hu, J. and Ye, G. (2013), The pore structure and permeability of alkali activated fly ash. Fuel, 104, p.771-780.
- Nguyen, V.P., Stroeven, P., Sluys, L.J. (2012), Multiscale failure modeling of concrete: Micromechanical modeling, discontinuous homogenization and parallel computations. Computer Methods in Applied Mechanics and Engineering, 201-204, p.139-156.
- Šavija, B., Pacheco, J. and Schlangen, E. (2013), Lattice modeling of chloride diffusion in sound and cracked concrete. Cement and Concrete Composites, 42, p.30-40.
- Tsouvalas, A. and Metrikine, A.V. (2014), A three-dimensional vibro-acoustic model for the prediction of underwater noise from offshore pile driving. Journal of Sound and Vibration, 333, p.2283-2311.

2.2.2 CLUSTER ENGINEERING STRUCTURES

Structural and Building Engineering
(Prof.dr. M. Veljkovic, Prof.dr.ir. D. Hordijk, Prof.ir. R. Nijsse, Prof.ir. A. van der Horst, Prof.dr.ir.J.-W. van de Kuilen)

The research focus of the group is on two main areas: improvement of functionality and maintenance assessment of existing infrastructures, particularly identification of unused capacities and improvement of resistance models for existing bridges, and influencing implementation of sustainable technical solutions in new structures by providing experimental and numerical research results. The following research lines can be distinguished:

- Assessment of real structural capacity of existing structures;
- Use and upscaling of new and existing materials (e.g. very high strength steel and concrete, fibre-reinforced polymers, glass and bio-based materials) in new, innovative and sustainable, structures;
- Resilience of structures to ageing and fire;
- Development of new execution techniques based on (prefab) components and innovative joints, for reduction of construction costs and enabling circular use of materials (re-use in addition to recycling).

Pavement engineering
(Prof.dr. A. Scarpas, Prof.dr.ir. S. Erkens)

The research focus of the group is the development of computational and experimental techniques capable of addressing the short and/or long-term response of materials typically used in the layers of Dutch and European pavement profiles at various material scales. The pavement materials vary from (partially) saturated soils, granular materials to bound materials like concrete and various types of asphalt. The group has a broad variety of experimental tools (e.g. to determine the healing capacity of bitumen, the interaction of stones and mortar on microscale and the development of skid resistance in asphalt), a unique software suite for Computer Aided Pavement Analysis (CAPA-3D) The following research lines can be distinguished:

- Improvement of existing and development of new, sustainable, pavement materials and structures, through the characterisation of (the interaction between) materials at various scales by means of experimental as well as numerical tools and validation of theories, models and innovations through large scale tests like the accelerated pavement testing facility, LinTrack;
- (remaining) Life-time prediction of existing pavement structures, in order to optimise maintenance costs, feed asset management systems and extend life span;
- Assessment and improvement of fatigue life time of pavement materials and structures.

Railway Engineering
(Prof.dr.ir R. Dollevoet, Prof.dr. Z. Li)

The research focus of the group is on theoretical and practical problems arising in railway operations in wheel-rail interface, train-track interaction, catenary-pantograph interaction and condition monitoring. The research addresses these problems at multiple scales from the operational level (CTO measurement train) to the nanoscale (CT-scan, SEM, ESBD, TKD, TEM). Real-life observations are transformed to laboratory dynamical testing (V-track) using advanced numerical models (WEAR, FE-Rolling) to laboratory dynamical testing (V-Track). The loading-degradation relationships acquired in the above-mentioned research are then utilised in developing sensing techniques for condition monitoring to preventive and predictively manage rail asset, by means of our patented technology of axle box acceleration (ABA) and laser Doppler vibrometry on moving frame (DrTrack).

The following research lines can be distinguished:

- Development of numerical procedures for solution of wheel-rail contact problems; use of the solution to understand the highly dynamic phenomena occurring at the wheel-rail interface, taking the coupled effects of the structures of wheel and rail into account;
- Understanding the degradation mechanisms of rails and wheels in relation to the different loading conditions and microstructures of the materials.
- Development of novel dynamics-based instrumentation and signal processing methods for earlier detection, diagnosis and prognosis of structure health, especially railway tracks;
- Data analytics for decision support of maintenance and renewal.

Cooperation of the cluster Engineering Structures with other departments

The groups of the cluster Engineering Structures have strong cooperative ties to other TU Delft research groups as the 3mE departments of Materials Science & Engineering and Microsystems Engineering, groups at the Faculty of Electrical Engineering, Mathematics and Computer Science, the Chemistry Groups at the Faculty of Applied Sciences and the Transport & Planning, Water Management and Geoscience & Engineering programmes at the Faculty CEG. Strong links exist with outside partners as the University of Twente, TNO, Deltares, TU Eindhoven, KTH Stockholm, Texas A&M University, University of California at Berkeley, TU Aachen, TU Dresden, TU München, Nottingham University and Chalmers University.

Key publications cluster Engineering Structures

- Lantsoght, E.O.L., van der Veen, C., and Walraven, J. (2013). Shear in One-way Slabs under a Concentrated Load close to the support, ACI Structural Journal, Vol. 110, No. 2, pp. 275-284.
- Yang, Y., Walraven, J., Den Uijl, J (2017), Shear Behavior of Reinforced Concrete Beams without Transverse Reinforcement based on Critical Shear Displacement. Journal of Structural Engineering, 143 (1) Article nr. 04016146.
- Teixeira De Freitas, S, Kolstein, MH, Bijlaard, FSK (2012). Structural monitoring of a strengthened orthotropic steel bridge deck using strain data. Structural Health Monitoring: an international journal, 11(5), 558-576.
- Qiang, X, Bijlaard, FSK, Kolstein, MH, (2012). Post-fire mechanical properties of high strength structural steels S460 and S690. Engineering Structures, 35 (February), 1-10.
- Molodova M., Li Z., Núñez A. and Dollevoet R. (2014). Automatic detection of squats in railway infrastructure. IEEE Transactions on Intelligent Transportation Systems, Vol. 15, No. 5, pp. 1980-1990, DOI: 10.1109/TITS.2014.2307955.
- Zhao X., Li Z. and Liu J. (2012). Wheel-rail impact and the dynamic forces at discrete supports of rails in the presence of singular rail surface defects. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit, Vol. 226, No. 2, pp. 124-139, DOI: 10.1177/0954409711413975
- S. Nahar, M. Mohajeri, A. Schmets, A. Scarpas, M. van de Ven and G. Schitter, "First Observation of Blending-Zone Morphology at Interface of Reclaimed Asphalt Binder and Virgin Bitumen", Transportation Research Record: Journal of the Transportation Research Board, Vol. 2370, 2013, DOI: 10.3141/2370-01
- Liu, X., Tzimiris, G., Scarpas, A., Li, J., "Analysis and assessment of fatigue response of multilayer asphalt surfacing system on orthotropic steel deck bridge with the five-point bending beam tests", Journal of Testing and Evaluation Vol 44 (3), pp. 1205-1216, 2016

2.2.3 CLUSTER INTEGRAL DESIGN

Integral Design & Management (Prof.dr.ir. M. Hertogh, Prof.dr. H. Bakker, Prof.dr.ir. R. Wolfert)

The research focus of the group is on two areas:

- Integration of multi-disciplinary, - actor, -modal and -functional aspects to achieve integral and adaptive designs and execution with high appreciation levels of stakeholders, as opposed to the classical approaches as decomposition (systems management), sequencing and a top-down (waterfall) approach;
- Improvement of management of (public) infrastructures and the optimisation of the quality of their engineering assets service levels, resulting in state of the art solutions, methodologies, models and or tools supporting effective and efficient planning, monitoring and operating of infrastructure networks and their assets.

The following research lines can be distinguished:

- Design methodology in an integrated context and initiation and implementation of integrated designs (e.g. by means of research by design);
- Current replacement and renewal programme for aging infrastructures with an additional challenge to add extra value to these infrastructures (such as multi-usability, and sustainability);
- Success factors for project management of large (infrastructural) projects, i.e. relational contracting, fit-for-purpose approach and inter-project learning;
- Plan & decide;
- Control & assess;
- Execute & optimise.

Cooperation of the cluster Integral Design with other departments

The groups of the cluster Integral design have strong cooperative links with all programmes of Civil Engineering. Strong links also exist with outside partners as LIACS Leiden University, Econometrics Institute Erasmus University, University of Western Australia (M017) and 5 Chinese high-ranking universities

Key publications cluster Integral Design:

- Koops, L., M. Bosch-Rekveldt, H. Bakker, M. Hertogh, 'Exploring the influence of external actors on the cooperation in public–private project organizations for constructing infrastructure', International Journal of Project Management, 35 (2017) 618–632.
- C. Demirel, W. Leendertse, L. Volker, M. Hertogh, 'Flexibility in PPP contracts – Dealing with potential changes in the pre-contract phase of a project' (2017), Construction Management and Economics. 35, 4, p. 196-206.
- Van den Boomen, M.; Schoenmaker, R.; Wolfert, R.: A life cycle costing approach for discounting in age and interval replacement optimisation models for civil infrastructure assets. Structure & Infrastructure Engineering DOI: 10.1080/15732479.2017.1329843.
- Leontaris, G.; Morales-Nápoles, O.; Wolfert, A.R.M.: Probabilistic scheduling of offshore operations using copula based environmental time series : An application for cable installation management for offshore wind farms. Ocean Engineering, 125 (2016), p. 328-341.

3 Societal Relevance

In § 3.1 the results and developments on the overall programme level will be discussed, results and developments on cluster level are discussed in § 3.2.

3.1 Structural Engineering programme

3.1.1 STAKEHOLDER ANALYSIS

As stated in the introduction, the research areas of the Structural Engineering programme are of utmost

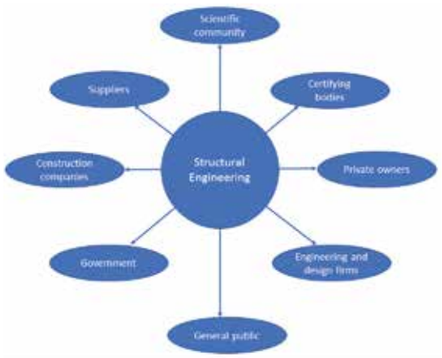
Relevant performc nce indicator.

	Quality domains	
Assessment dimensions	**Research quality**	**Relevance to society**
Demonstrable products	Research products for peers • Number of scientific publications • Number of PhDs graduated • Software packages and experimental equipment developed	Research products for societal target groups • Number of articles in professional journals and journals for the general public • Number of conferences organised
Demonstrable use of products	Use of research products by peers • Number of citations • H-index top 4 professors	Use of research products by societal groups • Total funding from contract research • Number of spin-off companies
Demonstrable marks of recognition	Marks of recognition from peers • High-level personal grants • Number of national and international awards • Membership of committees, editorial boards and research assessment panels	Marks of recognition by societal groups • Number of part-time professors with links to institutes/industry • Number of PhD students paid by industry • Membership national and international committees (including contribution to norms and standards

importance for design, construction and maintenance of vital (infra)structures in a densely populated country as The Netherlands, and internationally. The programme also addresses topics like reducing (societal) costs and environmental impact of maintenance and construction activities.

Achieving implementation of research results, creating societal impact, requires close ties to the major stakeholders. Figure 3, schematically maps the different groups of stakeholders. Cooperation with stakeholders is sought throughout the whole chain of events, from agenda setting, project conception to project execution and knowledge dissemination to implementation in standards and regulations.

Stakeholder analysis



Public and private asset managers as Rijkswaterstaat, ProRail, Port Authority Rotterdam, Schiphol Airport, industry (Shell, DSM etc.) and management authorities of regional governments and cities are responsible for a large stock of vital civil infrastructures. Major strategic challenges for these organisations are increased use, ageing and increase of loading of existing infrastructure. The results of our research enable their strategic decision-making and their procurement of new techniques.

Policy development on national and European level have a strong influence on the stakeholders in the research area of the Structural Engineering programme. Governments set goals for efficient use of resources (with the ambition of full circularity in 2050), adaptation to climate change and the transition to sustainable energy. These goals create challenges from the level of materials and structures to project execution and cost control. The groups of the programme work closely together here with materials and equipment suppliers, engineering and design firms, and construction companies.
In various sectors, certifying bodies or sector organisations that define norms and standards are active. The Structural Engineering programme already

Relevant indicators for societal relevance.

Indicator	Number realised
Patents	11
Software packages	3
Spin-off companies	3
Part-time professors with links to institutes/industry	10
Publications in professional journals	202
Publications in media for the general public	176
Membership international committees	19
Membership national committees	12
International conferences organised	23
International courses organised	6

seeks contact with such organisations in the early phases of research. Cooperation drastically enhances the chance of research results being embedded in new standards and norms. Researchers of the Structural Engineering programme actively participate in sector organisations' working groups, both to further promote the use of research results in standards and norms and to influence agenda setting of the sector organisation. Important here is that in many cases, government representatives also participate in such working groups.

Last but not least, the Structural Engineering programme functions as an independent expert. A recent example is the damage from earthquakes caused by gas extraction. The programme was active in model development and experiments connected to the prediction of loading from the earth quakes, the prediction of the remaining capacity of affected structures and infrastructures and finding solutions to improve resilience of buildings and infrastructure.

In the following paragraphs, indicators for societal relevance and achievements on these indicators will be discussed on the overall level of the programme. In §3.2, details will be given for the research clusters.

3.1.2 RELEVANT INDICATORS

The table on the previous page lists the indicators of research quality and societal relevance considered relevant to the Structural Engineering programme. Indicators of research quality have been discussed in the previous paragraphs. In this paragraph, we further discuss indicators of societal relevance.

3.1.3 ACHIEVEMENTS ON INDICATORS AND OUTLOOK FOR THE NEXT 5 YEARS

The table above summarises the achievements on relevant indicators for societal relevance. Details are given in annex 2.

Outlook for the next 5 years

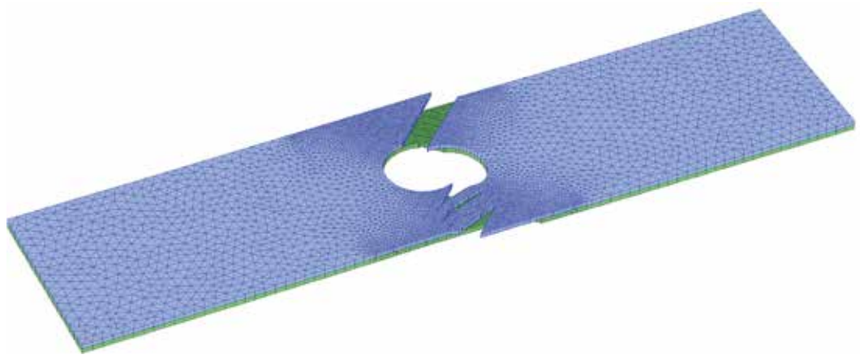
It can be expected that the formulation of the themes and the organisational measures to develop large multidisciplinary projects in close cooperation with stakeholders will further strengthen the programme's often leading role in numerous committees. The rejuvenation of staff means that more and more junior staff members will be taking over the role of the senior staff members. Point of concern is the level of Dutch with respect to national committees, as the influx of junior staff members is more and more international. Another point of concern for the coming period is the balance between part-time professors and full-time professors. Part-time professors can provide strong relationships with industry and institutes, but if the number becomes too large the managerial load for full-time professors becomes too heavy.

3.2 Research clusters

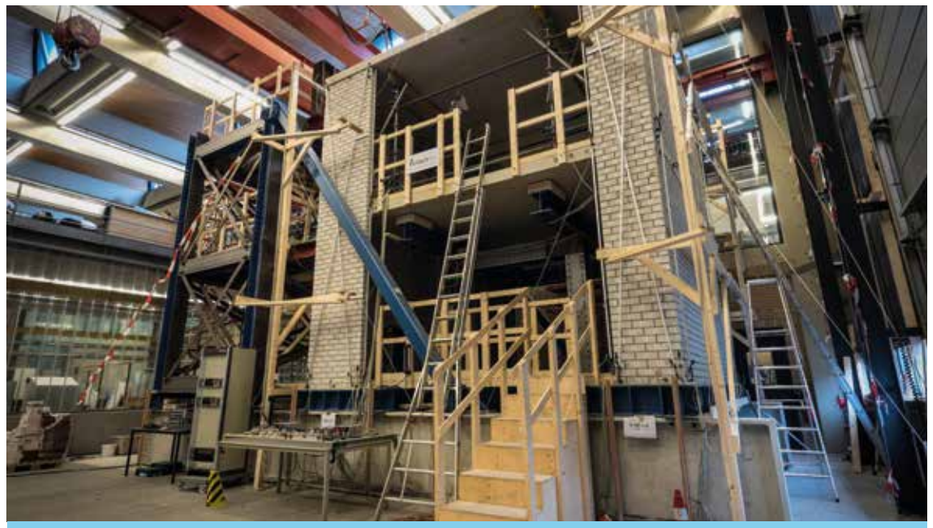
3.2.1 CLUSTER MECHANICS & MATERIALS

Materials & Environment

In the Materials & Environment programme, attention is focused on better recyclability of existing materials, lighter materials and reduction of footprint of the construction industry demands new materials, reduction of use of raw materials and reduction of emissions. With respect to research on

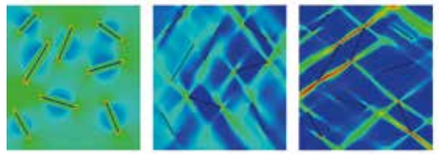


Frans van der Meer - Veni (see page 100, personal grants)
In 2012 The Netherlands Organisation for Scientific Research (NWO) has awarded 11 promising TU Delft researchers a Veni subsidy. Veni subsidies amount to a maximum of k€250 and are one of the 'personalised' NWO forms of stimulating scientific talent. Frans van der Meer was one of them. His research topic is "Simulations of tear development in composites". Light, fibre-reinforced composites are promising construction materials. However, it is hard to predict how strong a composite structure will be. This study uses a new, detailed computer model to calculate how much energy is required to tear the material.



Testing facility for earthquake resilience on full scale (see page 99, research facilities)
Since 1960 NAM (Shell, Exxon, Netherland's Government) extracts gas from the Groningen field, the second largest gas field in the world. This gradually led to shallow induced seismicity. Since the Huizige earthquake in 2013 (magnitude 3.6), this dominates the national agenda and gives high societal unrest. A team of postdocs, staff members, PhD students, lab staff and students tests and analyses masonry materials, wall and floor components, connections and complete houses. This multi-scale characterization of the building stock serves as input and validation to assessment methods and new nonlinear modelling techniques applied by consultants. End products are guidelines in the national annex for seismicity. TU Delft wrote the framework for damage assessment and damage claiming regulations on its scientific research.

Open technology grant for Karel van Dalen and Michaël Steenbergen (see page 100, collective grants)
In 2017 573.160 euros was award from the NWO Open Technology Programme to the project 'Rapid Degradation of Railway Tracks on Soft Soils Explained and Mitigated: Multiscale Dynamics, a Novel Approach". PI's and initiators are assistants professors Karel van Dalen, of the Structural Mechanics Group and Michaël Steenbergen, of the Railway Engineering group, supported by full professors Andrei Metrikine and Rolf Dollevoet of the same groups. The project is an example of opportunities created for young researchers and of multidisciplinary cooperation.



Angelo Simone – ERC Consolidator (see page 100, personal grants)
Angelo Simone was among the top scientists to be given a grant during the ERC Consolidator Grant Competition 2014. With this grant of k€2,000, Simone was able to attract 9 PhD's and 2 Postdocs to explore a new type of battery, which could significantly reduce the weight and size of our portable electronic devices. This "structural battery" will combine the structural function of a mobile device's housing with its energy source, thus significantly reducing weight and size of the device it's used for and enable manufacturers to alter the appearance of consumer electronics. Angelo feels " honored and privileged". Competition was fierce, with a success rate of just 8.5%. This funding "allows me to develop my own research team and gives me the freedom to pursue curiosity-driven research without any industrial obligation" he says.

NOW-TTW-Perspective grant for EUROS (see page 100, collective grants)
In 2015, 2 million euros was awarded from NWO-TTW Perpective programme to "Euros -Excellence I Uncertainty ERduction of Offshore Wind Systems'. Central theme of the EUROS-programme is reducing costs for offshore wind installation and maintenance, by removing uncertainties I design and imoproving predictions of weather conditions and remaining service life. In total 10 PhD students and 3 postdocs are active in the programme. Andrei Metrikine heads the research 'Loads and Damages', combining physical modelling and smart monitoring. Contributing lead researchr of the Structural Mechanics group, participating researchers are prof. Bert Sluys, dr,. Eliz-Mari Louresn, and prof. Rogier Wolfert. Andrei:"large multiscale programs like EUROS with a broad consortium of universities, researcu institues and strong inidstry partners offer excellent opportunities to make real steps forward and to develop young researcher's skills in linking their research to other disciplines.

materials, significant progress has been made in the application in practice of new (bio-based) materials and self-healing materials and in improved recyclability of materials and recycling of building materials including the implementation in practice.

A successful spin-off company was established on self-healing materials: Green Basilisk (elected to be among the top-3 most innovative medium and small-sized companies in The Netherlands). Erik Schlangen gave a successful TEDxDelft presentation, featured among the presentations selected by TED editors on the home page.

Structural Mechanics
In the Structural Mechanics programme, specific interest is given to new and innovative civil engineering structures and high-performance materials, contributing to lighter and less materials-intensive building of structures, thus contributing to societal demands for safe, reliable and resilient structures. The knowledge created was applied and extended to the case of damage from earthquakes caused by gas extraction in the northern part of the Netherlands.

3.2.2 CLUSTER ENGINEERING STRUCTURES

Structural and Building Engineering
The research has a close connection to the implementation of the outcomes of fundamental research into applications. The group, in close cooperation with major stakeholders like RWS, ProRail and the Port of Rotterdam, defines challenges connected to existing and new infrastructure and building concepts. Examples of joint projects are:
- Application of new ways of predicting remaining capacity and life span of concrete and steel infrastructures;
- Application of monitoring techniques for new and existing (concrete) structures for better assessment of life time and improvement of asset management policies;
- Application of new materials and construction techniques for faster construction.

Pavement Engineering
The Pavement Engineering group focusses specifically on new or improved pavement materials and structures that reduce the environmental impact of pavements by reducing emissions, noise and the use of raw materials while retaining the required technical quality and the prediction and assessment of (remaining) life time of pavement structures through advanced monitoring and data-analyses combined with laboratory tests and numerical models. The group developed test equipment and software, now used by the sector and students:
- SRITD (Skid Resistance Interface Testing Device) to test skid resistance of Asphalt Concrete;
- MAT device (membrane adhesion tester) to assess asphalt structures for steel bridge decks;
- A shear sensor developed to assess interlayer shear in full scale pavement structures;
- CAPA-3D, Finite Element Program, used by students and various international research groups to analyse pavement structures, using advanced material models for pavement materials.

Railway Engineering
The new knowledge, technology and methods developed by the Railway Engineering programme are often directly applied to engineering practice for preventive and predictive maintenance of asset, so that the life span, availability, sustainability and durability of the infrastructure are increased, and the emission and costs are tremendously reduced. Developments implemented by the sector are:
- Axle box acceleration detection method that has been applied to condition monitoring of the Moerdijk bridge. Application of the method is extended to broad maintenance contract areas and to non-intrusive 24/7 monitoring;
- Laser Doppler vibrometry on trains to scan tracks for all-round precision condition monitoring;
- More resilient pantograph design in order to improve overhead wire lifetime, reducing costs, hindrance and use of materials.

3.2.3 CLUSTER INTEGRAL DESIGN

Integral Design and Management
The belief of the research group is that relying on best practises as obtained from current approaches, although a popular approach is not the road to success. Instead, we need 'next practises' for new approaches. The challenge is to find better (more value) designs and management solutions (collaboration between actors) for less money (life cycle), and to create project success. For this the research group collaborates with numerous actors in the industry, governments, and other stakeholders, as well as platforms such as NAP, DIMI, IPMA, InfraQuest, Neerlands Diep, AMS, NLPB, Bouwcampus, Netlipse, consortium of 5 Chinese universities. The work comprised both the analysis of past projects and introduction of new collaborative work methods in new projects. Typical examples are:
- Performing assessment and evaluation Sluiskil Tunnel project;
- Learning organisation project Gaasperdammertunnel;
- Vision development renovation and renewal programme Ministry of Infrastructure and Water Management.

4 Viability

4.1 Structural Engineering programme

Benchmark: NTNU Trondheim
Benchmarking can be done at two levels: comparison at the university level and comparison with a specific programme with similar characteristics.

At university level, the main indicators are h-indices, citations, employer reputation and academic reputation. The TU Delft ranks 5th worldwide in the "QS University Ranking Civil & Structural 2016" for Civil and Structural Engineering.
As benchmark programme the Norwegian University of Science and Technology (NTNU, Trondheim) was chosen. Besides its high international standing, there were several reasons to benchmark against NTNU:
- Norway is repeatedly recognised as the country with the highest standard of living and we wanted to know what this entails for the university employees and the operational protocols of the university;
- NTNU closely cooperates with SINTEF, which is a close analogue to TNO, a very important partner for Structural Engineering;
- The Faculty of Engineering Science of NTNU includes a Department of Structural Engineering and a Department of Civil and Environmental Engineering (two departments seemingly focusing on very similar topics).

Our main observations were the following:
- Assessment of the quality of the research at NTNU is organised by the Norwegian Research Council with similar procedures and criteria as in the Netherlands. The results of the comparison on scientific quality are mixed: NTNU has an excellent group of international standing working on impact dynamics and crash analyses. On the other hand, TU Delft scores higher in the domains structural dynamics, applied mechanics and engineering materials;
- In general, the research of the Structural Engineering department at NTNU is more application-oriented than the research of the Structural Engineering programme at TU Delft;
- NTNU is implementing a new recruitment strategy based on the search for high-quality international inflow of personnel. At TU Delft, we follow a mixed strategy in which we raise our own highly talented staff members and hire high potential staff members from outside;
- NTNU infiltrates more and more into the national industrial research market and is changing from a collaborator of SINTEF into its competitor. This is seen at NTNU as a good thing in a flourishing economic situation, but it is also dangerous in economically more difficult times;
- The PhD students at NTNU are partly funded by university grants and partly by external funding. The duration of the PhD trajectory is officially three years but in average PhD students take about four years to finish their PhD thesis. The length of the PhD study at TU Delft is slightly longer (on average 5.5 years). Furthermore, all PhD research at TU Delft is financed from external projects or students come on international scholarships. NTNU has not yet implemented strict regulations for the PhD students monitoring their progress and organising PhD education as done at TU Delft.

Based on the benchmark the following conclusions are drawn:
- At TU Delft, we will maintain and further strengthen the healthy mix of the fundamental and applied research and will not enter a competition with TNO;
- We need to become slightly more aggressive in hiring top international talents; this is realised at the level of TU Delft as a whole, and we will join this process. However, we still consider it to be very important to offer tenured positions to the most talented 'home-grown' researchers;
- We will keep participating in international and national funding schemes, making use of our excellent cooperation with the national industries for applying for national and international subsidies;

SWOT of the Structural Engineering programme.

Strengths • Large and broad coverage of the domain • Strong research tradition and scientific signature in both fundamental and engineering disciplines • Excellent research infrastructure • Good relation with strong major stakeholders, through collaborative projects, contract research and part-time professors • Good mix of fundamental and application-oriented research • Good mix of national, European and industry-funded research projects • Presence in international committees and working groups • High scientific visibility of staff members	**Weaknesses** • High managerial burden on senior researchers / full professors; • High work load with respect to education and acquisition of projects • On average, long duration of PhD projects • Skills in developing integrated (multidisciplinary) projects and programmes together with stakeholders
Opportunities • Societal shift to zero-emission and circular economy • Societal pressure on stakeholders to change goals • Increasing possibilities for multi-disciplinary cooperation • Virtual materials testing partly replaces costly experiments • New types of contracts in the building and construction industry, triggering the industry to innovate	**Threats** • Decreasing research funding opportunities at national level • High percentage of permanent staff costs should be covered from 2nd and 3rd money stream projects • Difficulties to attract highly qualified research staff

- We will maintain the tradition of funding PhD studies from external grants. However, taking example of NTNU, we will consider creating seeding university grants for funding the first PhD year of PhD of outstanding internal graduates.

SWOT analysis Structural Engineering programme
The strong scientific position in combination with well-developed networks and cooperation with sector partners puts Structural Engineering in an excellent position to profit from outside developments (opportunities). However, really benefiting from the outside developments is hindered by an unbalance in work load (high workload related to education and high managerial burden of senior staff), and lack of skills in the development of (large) multidisciplinary projects and programmes. Given the fact that funding opportunities from NWO and H2020 are limited for Structural Engineering research subjects, the programme will have to find new approaches to leverage the strengths of individual groups. At the same time, a careful balance has to be maintained in the division of funding from 1st, 2nd and 3rd money streams to prevent erosion of the financial position by excessive cofunding obligations.

Strategy for the next 5 years
Asset owners and the construction industry will have to make rapid changes in the next decades. The top-level strategic development of the Structural Engineering programme is the gearing of research into three teams: resilience, integral design, and circularity. These themes reflect the main societal challenges in the building and infrastructure sectors. Thus, value for society can be expected to be high and this is also relevant for funding opportunities. Both nationally and internationally, governments and industry recognise the challenges and are willing to fund contract research or fund or participate in joint projects.

Structural Engineering develops new research topics and lines that fit to external trends, enabled by influx of new professors and subsequent research staff. Large programmes in close cooperation with other major stakeholders in the Netherlands already exist and will be extended by taking up opportunities for multi-disciplinary research in close cooperation with stakeholders. At the same time, efforts will be made to strengthen cooperation on the more fundamental aspects by defining new NWO-TTW (formerly STW) Perspective Programmes and, if possible, other large programmes.

Structural Engineering will also deliver input for agenda setting, in connection with national platforms, instead of merely following the national research agenda.

Relevant initiatives and platforms are:
- InfraQuest (strategic cooperation RWS, TNO);
- Bouwagenda;
- GROW (offshore wind);
- Digitalisation of Construction Industry;
- Building (The new Groningen Center for Earthquake resistance buildings and systems);
- 4TU.Bouw (faculties of civil engineering and built environment of the Netherlands Universities);
- 4TU.FSM (Fluid and Solid Mechanics);
- 4TU.HTM (High-Tech Materials);
- Graduate School on Engineering Mechanics (cooperation Eindhoven University of Technology, Delft University of Technology and University of Twente);
- Taskforce Bouw, chaired by former chairman of VNO-NCW: Confederation of Netherlands Industry and Employers;
- Round tables on circular economy within the framework of the National Research Agenda;
- DIMI TU Delft Deltas Infrastructures and Mobility Initiative with currently three big programmes: urban infrastructures, innovation airport and urbanising deltas, all with strong links to the programme.

4.2 Research clusters

In the following paragraphs, our viability will be discussed at the level of the individual clusters. The focus is on new developments in the research lines; other aspects such as viability in terms of personnel and finances have been discussed in previous paragraphs.

4.2.1 CLUSTER MECHANICS & MATERIALS

Materials & Environment
The Materials & Environment programme focuses on better recyclability of existing materials, lighter materials and reduction of footprint of the construction industry demands new materials, reduction of use of raw materials and reduction of emissions. New developments are:
- Geopolymers;
- Use of bacteria in self-healing concrete;
- Cementitious materials with improved characteristics;
- Improvement of recycling techniques of industrial and construction waste;
- Ageing of materials and structures and service life prediction.

Structural Mechanics
In the Structural Mechanics programme, specific interest is given to new and innovative civil engineering structures and high-performance materials, contributing to lighter and less materials-intensive, safe, reliable and resilient structures. New developments are:
- Computational modelling of structural batteries, leading to strong and stiff structures with reduced use of materials;
- Earthquake engineering, drafting new design tools, in the assessment of the vulnerability of existing buildings to earthquakes, in assessing the usability of strengthening measures and in evaluating the safety of crucial industrial process and storage facilities;
- Micromechanics-based modelling of rotor blade design and computational models for CO_2 sequestration;
- Smart monitoring and design of structures for the energy transition;
- Research on structural response to induced seismicity will be continued with upgraded multi-scale modelling methods and new experimental techniques including digital image correlation for crack detection, on-site proof and destructive testing, Hexapod multi-directional testing and a shake table. A shift will be made from assessment of as-built configurations to strengthening and upgrading.

Floating homes for the Philippines

Pieter Ham & Rob Nijsse

For the people living in the cities of the Philippines coping with the consequences of flooding has become a way of life. PhD Pieter Ham, under the guidance of professor of Structural and Building Engineering Rob Nijsse, is working on the construction of sustainable, modular homes in the Philippines. Floating homes.

www.tudelft.nl/en/ceg/research/stories-of-science/floating-homes-for-the-philippines/

4.2.2 CLUSTER ENGINEERING STRUCTURES

Structural and Building Engineering

The programme of Structural and Building Engineering focuses on improvement of functionality, monitoring and maintenance assessment of existing infrastructures and implementation of sustainable technical solutions in new structures. New developments are:

- Research into ecological concrete for sustainable structures;
- New and innovative approaches of assessing and improving fatigue lifetime predictions of steel bridges;
- New execution techniques based on (prefab) components and innovative joints;
- Use of natural fibres in engineered new bio-based building materials and composites for structural applications;
- New scanning techniques using 3D laser scanning for assessment of structural elements.

Pavement Engineering

The pavement engineering programme focuses specifically on new or improved pavement materials and structures that reduce the environmental impact of pavements by reducing emissions, noise and the use of raw materials while retaining the required technical quality and the prediction and assessment of (remaining) lifetime of pavement. New developments are:

- Research on raising levels of reclaimed asphalt (>80%) in new asphalt;
- Assessment of alternative and modified asphalt binders, using among others rejuvenators, crumb rubber, lignine and epoxy;
- New, life-extending maintenance techniques that can be applied on all (i.e. rejuvenators) or specially prepared (i.e. induction healing) asphalt pavement materials;
- Improved models and test methods on various scale to assess the expected and remaining service life;
- Use of innovative materials and techniques for the improvement of noise reduction.

Railway Engineering

In the Railway Engineering programme, the focus is on wheel-rail interface, train-track interaction, catenary-pantograph interaction and the condition monitoring based thereupon. These lead to new technology and information for preventive and predictive maintenance of asset, so that the life span, sustainability and durability of the infrastructure are increased, and the emission be tremendously reduced. New developments are:

- Technological innovations for rail systems by new monitoring techniques, coupled to thorough and fundamental knowledge of wear and fatigue caused by wheel-rail contact, thus increasing the operationability of rail systems, reducing costs an use of materials;
- Decision support and key performance indicators design for best whole system performance in order to maintain the highest possible availability of the rail system for lowest (societal) costs;
- More resilient pantograph design in order to improve overhead wire lifetime, reducing costs, hindrance and use of materials;
- Future and new concepts of mobility on rails;
- Image recognition for automatic detection of rail defects.

4.2.3 CLUSTER INTEGRAL DESIGN

Integral Design

The research of the group focuses on integration of multi-disciplinary, -actor, -modal and -functional aspects to achieve integral and adaptive designs, and improvement of management of (public) infrastructures and the optimisation of the quality of their engineering assets service levels. New developments are:

- Increasing importance of maintenance of the present assets;
- Increasing awareness of project principals for the need of an integral approach of spatial and disciplinary aspects;
- Increasing trend toward putting aesthetics first in design of new structures and infrastructure.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