Research Report Civil Engineering

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Cases studies and summaries

Department of Engineering Structures

Department of Hydraulic Engineering

Department of Transport & Planning

Department of Water Management

Department of Materials, Mechanics, Management & Design

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1.

Department of Engineering Structures

Case study 1

Concrete to Cement & Aggregates (C2CA) technology for circular concrete

Supply for concrete jeopardised

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

Circular concrete to combat resource shortage

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

Technological innovations to optimise reuse

The transition to a share of 30% circular concrete in Europe by 2030 requires major innovations, including regulatory frameworks, digitisation, and physical and chemical processing technologies. Technological Innovations range from the inventory and smart dismantling of End-of-Life buildings to the production and quality control of high-grade sand, gravel and binders from real-life waste concrete. The C2CA series of technologies aims to improve the last part of this chain by separating cement-rich fine fractions from waste concrete. Some technologies focus on finding the perfect source for the new generation of concrete with the right mechanical and engineering properties. Other C2CA technologies aim to develop a tracking system based on radio-frequency tags to monitor product flows and quality to support automated production. Realising a sustainable solution based on the circular economy is now a step closer, eliminating polluting production processes, reducing transport and greenhouse gas emissions, and converting concrete waste into a new concrete product. This transformation will contribute to achieving the European target of facilitating the large-scale throughput of green and recycled construction materials.

C2CA technologies enter the market

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

Case study 2

Gentle Driving of Piles (GDP) Technology

Offshore wind with less disturbance to marine life

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

Patented technology supported by international alliance

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

GDP is developed with funding and support from the Netherlands Enterprise Agency (RVO - Rijksdienst voor Ondernemend Nederland) and the international GROW consortium that encompasses twenty leading and committed international partners that cooperate closely to conduct joint research in Offshore Wind. The GDP journey started in 2018 with a EUR 4 million project. After several follow-up projects (i.e. the EUR 6 million SIMOX), a GDP 2.0 project is due

to start soon aiming at demonstrating the technology offshore at a 50% scale. The goal is to get the technology market-ready by 2027 by means of mutually beneficial cooperation between the **ES department, the GROW** consortium and recently established Vibrotwist spin-off company.

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

Successful contribution to the energy transition

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

Summary

The mission of the department of Engineering Structures (ES) is to provide world-class scientific innovation to assess the integrity of the built environment, to support mitigation strategies for climate change, and to tackle urbanisation challenges due to a growing world population. The ES department aims to develop solutions for resilient, smart and sustainable (infra) structures that meet societal demands in transportation, energy transition and sustainable reuse. The research agenda of ES is mainly composed of two parts: (i) the modelling and (ii) the experimental characterisation of mechanical behaviour of materials and structural components.

The experimental part of the research is performed in the Macromechanical Laboratory (MacroLab). The research activities are also inherently linked to educating the new generation of engineers and scientists.

The ES department consists of eight sections, covering four overarching scientific and societal themes. These themes encapsulate both the pursuit of scientific innovation and the need to meet current and future societal needs, at national and international levels, concerning sustainability, urbanization challenges and the transition to renewable energy systems. The four themes are as follows: a) Structures for energy transition; b) Recycling and circular structural systems; c) Transport infrastructures for a future-proof built environment; d) Structural integrity through innovative monitoring, damage assessment, prediction, and maintenance. Each theme is strongly linked to traditional disciplines of mechanics of materials, solids and structures, and transport systems science, focussing on the integrity of existing and new structures

To accomplish the mission, the ES department has set six strategic aims. The first aim (1) is to support and consolidate the four aforementioned themes to strengthen the department's leading position, both at a national and international level. The second overarching aim (2) is to translate research results into effective technologies, thereby facilitating the development and subsequent transfer of knowledge to the industry. The third overarching aim (3) is to work across different TRLs (Technology Readiness Levels), covering both curiosity- and application-driven research. The fourth aim (4) is to strengthen inter- and intra-departmental collaboration to jointly progress in the identified themes. This allows us to tackle scientific challenges from a multidisciplinary perspective. The fifth strategic aim (5) aligns with one of the Faculty aims, envisioning the growth of an inclusive academic culture. The final strategic aim (6) is to achieve a healthy financial balance between the different revenue streams to support aim (3).

The department pays special attention to application-driven research projects without weakening the connection to curiosity-driven research. The projects of all eight sections contribute to each theme in a complementary manner, showcasing the strong cross-link between staff members and scientific themes. This is made possible thanks to the extensive MacroLab facilities, which allow each section to carry out experimental work spanning a large spectrum of different Technology Readiness Levels (TRLs), ensuring a strong balance between traditional disciplines of structural engineering and the identified themes. Considering the broad spectrum of projects, the ES department demonstrates its ability to connect and partner with major stakeholders in the field of interest and secure funding through a good combination of national, European, and industry-funded projects. Two case studies (XXX and XXX) demonstrate the commitment of the department towards highly scientifically and socially impactful activities, while the number of awards, spin-offs, collaborations with industry, and patents show the overall impact the department has made over the last few years. Apart from research activities, ES has employed a diverse range of strategies such as master classes, Massive Open Online Courses, media engagement, and contributions to informing standards, demonstrating its effort to contribute to the larger societal context. Initiatives such as the Young Management Team promote young staff members to actively participate in various decision-making processes of the department.

In the future, the ES department will work on ensuring a leading position within the four themes via its six defined aims. These themes become inherent connections to the societal need to shift towards a circular economy and the need for the safety and security of existing and new infrastructures. Further opportunities to seek alignments among the themes can be exploited thanks to the ongoing trend to embed new developments in computer science (AI, ML) in engineering structures.

2.

Department of Hydraulic Engineering

Case study 1

2021 Floods Fact-finding Taskforce

Information gathering directly after floods

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

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

Insights form basis for evaluation and improvement

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

Measurement data showed that the peak discharge of the Meuse River and several of its tributaries reached record levels. The study also provided insight into the performance of infrastructure, showing that the primary flood defences along the Meuse effectively withstood the exceptionally high loads well, but that incidents and local height deficiencies did occur in some places and specific temporary measures were deployed on a large scale. The estimated total damage amounted to EUR 500-600. To gain insight into the health impact, the HE team collaborated with Erasmus MC as part of the Pandemic and Disaster Preparedness Centre (PDPC). It was shown that COVID transmission was higher in the most flooded areas than elsewhere. The findings of the Taskforce are now being used to evaluate the system and identify technical, spatial and organisational improvements.

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

Enhancing preparedness for future flooding events

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

Case study 2

SALTISolutions (Salt Intrusion through Urbanising Deltas: Solutions)

Salt intrusion threatens freshwater availability

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

The Virtual Delta

The SALTISolutions research programme aims to empower hydraulic engineers and provide insights for decision making for a liveable future Delta. This EUR 6.68 million, six-year, NWO-funded Perspective Research Programme is led by Prof. Julie Pietrzak (HE) and unites leading national experts from the universities of Eindhoven, Wageningen, Utrecht, Twente and Delft.

Together with our partners Rijkswaterstaat, Deltares, Dutch consultancy firms, water boards, port authorities and dredging companies, SALTISolutions will produce ‘VirtualDelta‘, a digital twin of the Rhine-Meuse Delta. The programme is curiosity driven and application inspired, the latter feeding off the former. Intended breakthroughs range from novel parameterisations of turbulent mixing processes and complex river junctions to new insights into coupled delta-ocean interactions, including under extreme climate change. The understanding of freshwater in the Dutch and other deltas will help to pioneer new nature-based solutions and mitigation strategies. We will use what we learn in SALTISolutions to train a new generation of Hydraulic Engineers, who are confident in the new fields of digital twins and Artificial Intelligence and have a deep understanding of physical processes and mitigation and adaptation methodologies.

Unique field campaign provides crucial knowledge

In 2022, an important step has been taken towards the digital twin with the deployment of a major field campaign around the mouth of and within the Rotterdam Waterway. The campaign was initially planned for 7 weeks, but due to the unprecedented drought, it was continued for 17 weeks. It led to the collection of a unique data set of temperature, salinity, currents, and turbulence, that will provide crucial knowledge to advance our physical understanding of the system and how to model and manage it.

Better prepare society for future salt intrusion events

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

Summary

The mission of the HE is to educate world-leading civil engineers, train academic scientists and create scientific breakthroughs by carrying out world-class research'. This is achieved by combining fundamental science with engineering and design, understanding of natural systems and consequences of interventions, developing numerical and experimental tools to validate and substantiate the knowledge, translating and integrating research findings into impactful solutions.

HE aims to develop state-of-the-art engineering solutions for high-water safety, nature-based development, water-borne transport and renewable energy, based on a thorough understanding of natural system dynamics, its response to interventions and infrastructure design. HE's joint research themes are found across the sections and link advances in fundamental science to real-world applications with key focus on the development of generically applicable modelling tools and design guidance. These four overarching research themes are: 1) Dynamics of marine and fluvial systems, 2) Sustainable infrastructure and nature-based solutions, 3) Climate adaptation and flood risk management, and 4) Renewable energy in the marine environment.

HE has produced >70 high-impact journal publications, > 30 Editorials, organized 19 conferences and delivered 69 PhD dissertations. Many staff members and PhD candidates have received international prizes for their research. Successful research worked as a seed for acquiring prestigious grants and showcase international leadership (10 personal grants, > 40 keynote lectures, > 50 External PhD committees).

Open Science: HE has strong emphasis in open source modelling tools (SWAN, SWASH, SOPRANO, Aeolis, etc), and has lab facilities (flumes, water labs) and large scale e.g. ZandMotor, which has gained an international reputation. The department is making continuous efforts to make its research results accessible to the scientific community and the general public. The percentage of journal papers with open access increased from 53% in 2017 to 76% in 2020. Over the period 2017 to 2020, 475of the 726 papers (65.4%) were published open access. The facilities, data and models, are made available for other researchers, that often have major collaborations. In addition, public outreach via social and other media has increased significantly.

PhD policy & training: PhD candidates receive structured support and supervision in order reduce PhD delays, in line with faculty ambitions for timely graduations.

Academic Culture: Influx of new staff members strengthening core disciplines. The department worked on ‘non-Delft’ diversity in staff (12 out of 14 new hirings were non-Delft), and aimed for a reduction of workload of staff members. Actions were taken to have a stronger involvement of young staff members in the department management and organisation. A discussion was started to realise better working conditions, enhance opportunities for staff members to build on their career. This was followed by regularly reflecting on wishes/needs and by offering personal training for professional development. Explicit attention was paid to the topic of diversity and inclusivity, amongst others by means of plenary discussions during the two-monthly staff meetings.

Human resources policy: HE played a leading role in faculty-wide revision of Academic Career Track policy, most notably the procedure for evaluation and the reduction of the length of the temporary employment from five to 1.5 years and the hiring of younger and new staff at HR functions.

Strategic goals for next six years:
The research agenda for the upcoming years is inspired by grand societal themes related to climate change, replacement of end-of-life hydraulic infrastructure, energy transition and loss of biodiversity.

1) Strengthen the leading position within the four themes (mentioned in Summary)
2) translate research results into effective technologies
3) include research activities across different TRLs
4) align the different sections to the four identified themes, foster interdisciplinary research
5) growth of an inclusive academic culture
6) reach a healthy financial status

3.

Department of Transport & Planning

Case study 1

Transitioning to low-car cities

Citizens reclaim public space

Cities across the world are transforming in order to become more pleasant places to live in, driven by people's wishes to reclaim public space and promote walking and cycling. The Netherlands has long been a pioneer in fostering a cycling culture, resulting in positive impacts on mobility costs, safety, and equality. In the 21st century, the country is facing another pivotal moment, prioritising active modes of transportation (like walking and cycling) and aiming to create car-free cities. The T&P department has played a leading role in researching and supporting the transition to low-car urban regions.

Realising smart mobility hubs in Amsterdam and beyond

Amsterdam, which wishes to ban cars by 2030, is a leading example. Several research projects led by the T&P department have sought to provide the puzzle pieces needed to reach that goal. To support the mobility needs of citizens, the T&P lab for Electric and Automated Transport (led by Correia and Martinez) has investigated the introduction of the concept of shared mobility hub, developing smart hubs and e-hubs that boast a combination of electric cars, electric bikes, and electric cargo bikes. Valuable insights have been gained about planning, facilitating, and responding to traveller behaviour. A direct impact on the uptake of shared mobility has since been observed. Tools to plan and deploy these hubs are now available for other cities in the Netherlands and around the world.

Pleasant and safe pedestrian spaces

The T&P department has developed unique knowledge of the challenges and issues that cyclists and pedestrians face. Our Active Mode Lab, led by Duives, studies the choices and behaviour of pedestrians and cyclists. In recent years, the Active Mode Lab performed multiple studies into

the route choice behaviour of these road users to identify elements of the urban environment that invite active mode users. The EIT-KIC-funded project CityFlows is an example of a project to improve the liveability of crowded pedestrian spaces by providing decision support tools to manage pedestrian flows. In another project, Artificial Intelligence technology was used to provide forecasts for managing crowds. The police now use this knowledge to plan their interventions and increase safety, which shows the direct impact of this research.

Mobility solutions in future situations

The transition to low-car urban regions has only just begun. Soon, the T&P department will start developing digital twins of low-car urban areas as part of the NWO Perspectief- funded XCARCITY project (led by van Arem and Snelder). These virtual models will shed more light on the effects of different mobility solutions and be used to test various scenarios and interventions for addressing specific problems in the cities of Almere, Amsterdam, and Rotterdam. In the coming years, the representation of mobility in the virtual world will take off and produce a wealth of invaluable simulated data, enabling us to investigate situations that do not currently exist and risks that we do not yet understand.

Case study 2

Mobility management during a pandemic crisis accept all

The pandemic and its effects on mobility patterns

The COVID-19 pandemic resulted in travel restrictions. Lockdowns and an increase in working from home drove people away from public transport. In the end, the pandemic has had a significant impact on entire transport and mobility systems. To address the resulting challenges, the T&P department has developed methods, tools, and empirical findings to support decision-making in mobility management. Investigating the relationship between mobility patterns, shifts in travel preferences and how viruses spread could help to improve traffic and mobility management during pandemics.

Shifts in travel preferences

The shifted travel preferences and changed behaviour appeared to be persistent, as indicated by extensive analysis performed by the T&P department. This analysis was part of the NS panel survey on COVID-19, in which train travellers were asked about their preferences and considerations. Urgent policy questions about mobility during the COVID pandemic were also addressed in the MOCOLODO project. The T&P department's overview papers on adapting transport schedules helped the public transport sector deal with the consequences of the crisis.

Insights to limit virus transmission

The SamenSlimOpen project developed quantitative models and software to identify the risk of spreading COVID-19 within indoor environments, such as in public transport. The conclusions were presented to policymakers and relevant interest groups to provide insight into the impact of crowd management protocols, access policies for (non-)vaccinated people (2G/2G+/3G), and ventilation on transmission risks.

At the national level, the T&P department led a consortium tasked with designing and implementing technology to keep schools and universities open during the pandemic. This led to the development of a monitoring system and a dashboard to track and visualise unsafe interactions between students, staff, and 'bubbles' (groups of people in which social distancing was not possible because of educational activities). This technology helped design optimal circulation plans and quarantine strategies.

Predicting traffic flows

As a result of these efforts, we now have unique datasets on the changes in travel demand and attitudes spanning the entire duration of the COVID-19 pandemic in the Netherlands. These data can be used to create models that predict behavioural changes. All data, models, and insights obtained during the pandemic have also been successfully used to predict traffic flows in crowded places in a more general sense.

Summary

Our goal is to develop sustainable solutions that address the complex challenges facing transport and mobility in modern societies in the best possible way by researching beyond-state-of-the-art methods and technologies. The research lab-based organization of the department aims to contribute to this objective by means of several thematic labs that focus on different societal challenges identified in the Faculty strategy, and methodological or mode-agnostic labs that develop and/or work with state-of-the-art methods and technologies.

Transport & Planning (T&P) addresses four main themes, which reflect the transition that T&P has made in the past decade in terms of the focal points of its research:

A. Urbanisation and Smart Sustainable Transport.
B. Climate-friendly Transport and Resilience.
C. Well-being, Health, Equity, and Digitisation in Transport.
D. Computational Modelling and Analysis for Transport Engineering.

During the assessment period from 2017 to 2022, the Department of Transport & Planning witnessed significant growth in scientific output and societal impact. Peer-reviewed journal articles increased from 87 to 122 annually, with PhD theses rising from 4.3 to 10 per year. Notable achievements include awards like Correia's 4th place in TRAVISIONS 2022 and Besinovic's 3rd place in the 2017 IEEE ITS Best Dissertation award. European grants, including 18 EC Horizon projects and two EC Interreg projects, accounted for 35% of total grant funding. Average yearly income saw a 60% increase, with personal grants such as Veni and ERC starting grants highlighting departmental accomplishments. Societally, projects like SamenSlimOpen addressed COVID-19 impacts, while collaborations with industry and public authorities ensured real-world solutions for transport issues. Open-access articles increased from 79% to 89%, with a significant media presence averaging 26 appearances per year, disseminating departmental developments widely.

Our PhD policy and training strategy for the coming years stresses quality assurance in recruitment, training and coaching. For the former, we will capitalise on the department's newly established guidelines for paper-based PhD theses. We plan to create an 'onboarding package' for new PhD candidates, reinforce the buddy-system and establish clear guidelines for expectations and the go/no-go procedure. Furthermore, we are committed to ensuring a smooth, transparent, and inclusive process for selecting and admitting PhD candidates.

In terms of academic culture, our strategy is to be firmly focused on the impact we are committed to creating and offering a merit-based, value-based, empathic and inclusive, and intellectually stimulating work environment. In the coming period, we intend to focus on improving the alignment of responsibility and accountability and the distribution of management tasks and responsibilities, including the mentoring of new members.

In relation to T&P human resources policy, our recruitment policy will follow our newly established process for the scoping of new positions where alignment with department strategy is key. Our commitment to diversity is an important part of our identity and is therefore also key in selecting new staff members.

Our strategy for the next six years:

- to maintain and strengthen our position as a world-leading group in transport research.
- to offer a vibrant, engaging, and inspiring environment for scientific talent.
- to contribute to and improve the capacity to address challenges and opportunities related to emerging technologies and societal changes.

4.

Department of Water Management

Case study 1

Circularity in the urban water cycle

Water scarcity calls for an improved urban water system

By 2025, two thirds of the world population could be affected by water scarcity and extreme water stress, posing a serious threat to the world's population. Especially in rapidly urbanizing areas, the implementation of sanitation and potable water infrastructure is not keeping up with population growth.

Historically, our urban water systems were designed to deliver potable water to the city and subsequently discharge it into open water bodies. However, our natural water resources have come under serious risk from (over)abstraction of source water from the surrounding environment (e.g., groundwater) and the discharge of polluted water. In a circular water system, we could reduce the city's water footprint by recovering water for reuse, as well as recovering the potential valuables it carries, such as nutrients and heat. Recovery of such valuables can contribute to achieving circular economies amidst the current energy and nitrogen crises as well as accelerating implementation of sewage water treatment globally. The WM department develops new technologies that can drive the recovery of water, nutrients and energy in cities.

Making the most of water usage

An entirely new method developed at WM generates electricity by fueling a solid oxide fuel cell with ammonia recovered from wastewater via vacuum membrane stripping. Removal of total ammoniacal nitrogen (TAN) is important to prevent environmental damage, but the treatment is very energy intensive. With this recently patented technology, the outcome of PhD research by Niels van Linden (see photo), TU Delft start-up MEZT is currently running a pilot with manure to reduce nitrogen emissions.

Another, completely different innovation is thermal energy recovery from drinking water distribution networks. This technology was developed by PhD candidate Jawairia Ahmed and has now been implemented by Waternet, Amsterdam's drinking water supply company Waternet. Ahmed investigated the potential consequences of elevated water temperatures after energy recovery for the microbial safety of tap water (e.g., Legionella growth).

The research on circularity also extends beyond the boundaries of the Netherlands, as is illustrated by the WM-led LOTUSHR project. In this project, funded by NWO and the Indian Department of Biotechnology, over ten PhD candidates work on water challenges in Indian megacities. In New Delhi, a living lab was constructed on the banks of the Barapullah drain with partner university IIT-Delhi. This water body is a huge open sewer that eventually feeds into the river Ganges, putting the health of millions at risk. In this living lab, visited in 2019 by King Willem-Alexander and Queen Maxima, novel technologies for the safe and socially accepted reuse of water can be tested.

A transition to a circular water system

WM develops state-of-the-art technology to foster the transition to a circular water and resources system. Research is typically conducted in close collaboration with stakeholders, including water boards, drinking water companies and tech companies. These collaborations have been shown to accelerate new technology adoption in the water sector, as well as allowing the WM group to tap into industry funding and infrastructure. As such, WM is able to translate fundamental research that advances scientific understanding into technological solutions that address societal challenges.

Case study 2

Rainfall mapping in Sub-Saharan Africa

African agriculture is mainly rain fed

In Sub-Saharan Africa, over 95% of the agriculture is not irrigated, but relies solely on rainfall. Accurate and timely rainfall mapping is urgently needed to develop climate services for (smallholder) farmers and for flood early warning systems. By establishing a sufficiently dense network of metrological stations, ground measurements and satellite-based geo-data could be used to build reliable weather models for sub–Saharan Africa.

Make farmers more resilient

The WM department has led several initiatives in this area, including the TAHMO initiative, which has established a network of about 650 low-cost weather stations (see photo) across East, West and Southern Africa. These stations measure currently unavailable geo-information on weather, water, and climate for locations in sub-Saharan Africa with additional innovative in situ sensors. This TAHMO network delivers services developed through the H2020 TWIGA project, including localized, timely weather forecasts, flood early warning and crop insurance and heat stress indices for livestock. These services have helped to increase the resilience of African farmers and citizens by enabling climate-smart decision-making on farm operations and insurance. The follow-on Horizon Europe TEMBO project is currently building cost-effective innovative sensors for the TAHMO network that can be financed by co-developing large socio-economic value in the fields of geo-hazards, reservoir management, and agricultural information services.

Insights into rainfall for ten African countries

At the UN's recent 2023 Water Conference, the WM department announced its commitment to install sufficient weather stations to cover at least ten Sub-Saharan African countries by 2030. This is an exciting and ambitious target, which the Department hopes to achieve together with the Kenyan Meteorological Society, Masinde Muliro University of Science and Technology (MMUST) and Jomo Kenyatta University of Agriculture and Technology (JKUAT).

Global water challenges

This WM research line illustrates the Department's long-term commitment to impact-driven research that addresses key international development challenges related to water. The department leads Water for Impact, a campus-wide TU Delft Global Initiative programme that connects water research with local and global impact by bringing together academic institutions, governments, NGOs and private sector organisations to co-create innovative solutions to global water challenges. Water for Impact aims to work on the water-related challenges such as hygiene, sanitation, pollution, flooding and availability for drinking and irrigation purposes and is active in an estimated 28 project countries, including Ghana, Mozambique, Zambia, Uganda, Brazil, Costa Rica, Indonesia, Bangladesh, Nepal and India.

Summary

The Water Management (WM) department leads in addressing water related challenges and developing innovative solutions, with two sections: Water Resources and Sanitary Engineering. Water Resources covers the entire terrestrial water cycle including major aspects of hydrology and water resources. Sanitary Engineering covers wastewater treatment, industry water, drinking water, and urban water infrastructure.
WM's unique strength is the wide range of water-related expertise within a single department, allowing to tackle global water challenges related to water quantity (floods and droughts), water quality (pollution, treatment, and reuse), and water infrastructure. This cross disciplinary research is organised around three societally relevant research themes:

- Water and Energy in urbanising Deltas (contributing to SDG 6, 7, 11)
- Water, health and Disaster preparedness (contributing to SDG 6, 13)
- Water, food and climate (contributing to SDG2, 13)

These themes directly contribute to water related challenges in low- and middle-income countries, where the need for solutions is most pressing. These themes stimulate cross disciplinary collaboration, and guide towards a shared longer term vision. As such, the themes can aid in strategic choices (e.g. new hires, joint project proposals). Furthermore, WM is united by common research methods (e.g. AI, real-time control), joint educational activities (i.e. MSc Environmental Engineering programme) and shared (lab)facilities.

The scientific quality of WM is illustrated by the increasing number of peer-reviewed publications: on average 214 peer-reviewed journal articles per year (155 publications/year during the previous assessment period), with a stable 20 PhD theses per year. Co-authors of WM publications included 548 external researchers, indicating that WM academic staff are well embedded and recognised in the scientific community. The scientific excellence is rewarded with personal research grants and awards by the international community.

WM strongly shares the "as FAIR as possible" principles and promotes open science. The percentage of open-access scientific publications by the department has grown from 59% in 2017 to 99% in 2022. The programme "water for impact" was launched, increasing the visibility of our internation research agenda, particularly our activities in Africa. The eWaterCycle project makes and shares open hydrological models and data for full reproducibility. The THAMO initiative shares openly its weather data with researchers and governments. Besides open science, WM is actively involved in open education via its four MOOCs and online professional education (3 courses).

Organisational strategy: The department shifted from traditional single PI leadership to a team-PI model, promoting flexible collaboration among staff across research themes. This flat and informal hierarchy fosters individual excellence while capitalizing on multidisciplinary expertise, enhancing inclusivity and sustainability.

Human resources policy: The department maintained a stable scientific staff, with a strategic increase in groundwater quality expertise. A strategic choice was made to improve the quality of our laboratory, increase the support staff from 2.9 to 6.9 fte. Efforts to enhance gender diversity led to more female senior staff, including a female Department Chair as historical first within the faculty. Diversity increased notably among non-Dutch academic appointments, as well as PhD candidates, with 46% female and 83% non-Dutch candidates, contributing to a more inclusive environment.

The department foresees a consistent strategy, focusing on enhancing current approaches like the team-PI model. Research will address water-related societal challenges like climate change, urbanisation, energy transition, the circular economy, (emerging) water contaminants, and digitisation (i.e. AI, big data).

Other strategic goals are:

- Increase departmental collaboration via the team-PI-structure, department strategic meetings and stimulating match making activities.
- Hire a balances ratio female/male staff members.
- Increased focus on reducing the duration of the PhD trajectory: to many PhDs exceed the 4 years currently
- Remain committed to open science, and intensified communication to the scientific community, authorities and technology providers

5.

Department of Materials, Mechanics, Management & Design

Case study 1

Research by Design for future proofing our cities

Cities face a multitude of societal issues and system transitions

The cities we live in, are not future proof. Several factors challenge the liveability, such as climate, biodiversity, circularity, inclusiveness and mobility. The population is expanding, housing is in short supply, and we also have to deal with heat stress, drought, and traffic jams. To deal with these widely divergent challenges, TU Delft has started to redefine them with an interdisciplinary approach. The Deltas, Infrastructures and Mobility Initiative (DIMI) uses Research by Design as a method for exploring tangible futures for problematic or favourable locations within the present built environment. Presenting inspirational integrated designs for cities challenged by a multitude of social issues and system transitions from different angles by starting an intersectoral dialogue. This offers policy makers, city management and other stakeholders the awareness of the potential power of integrated design for the contextual interpretation and (re)definition of societal challenges and its relevant aspects for an array of locations. Integration prevents that related problems are solved in isolation, causing sub-optimization.

Research by design as process and instrument to explore city's future

Research by Design is both a collaborative and interdisciplinary learning process as well the imagination how an urban location could look like after 20 to 30 years. The process includes analysis by joint fact-finding and lead to a shared vision, principles and design strategies.
The application of these by co-creation results in an integrated and tangible design which will be reviewed by involved stakeholders on basis of criteria related to spatial advantage, quality of the living environment, its future proof and feasibility for implementation. Designs can be made for different time spans, from the long term for futuristic explorations, and then backtracking to the current situation, to the short term by stepping stones in the process of preferred transitions.

DIMI publishes their results in accessible and reflective books and or essays to disseminate the practical lessons, education and research to a broader audience. This integration of tangible results and its reflection from a scientific perspective clarify the context and meaning of the results for practice. An editorial board assess plausibility of every book publication.

This available source of knowledge proves to be of considerable value for the recently established programme "Redesigning Deltas" of the convergence program Resilient Delta. The resulting designs have been creating impressive impact in the sector. It is an accepted methodology for spatial exploration of complex and uncertain developments by the Minister of Spatial planning and Housing (Ministry BZK) and the Topsector Creative Industry. Furthermore, the Board of State advisors (CRA) apply the method for advising ministries. DIMI played an important role in these developments.

The teams working on these projects are extremely diverse. For the project 'City of the Future,' the five biggest Dutch cities contributed, ten design teams from the sector (approximately seventy partner organisations) and many academics. Also, eighty civil engineering students of the first-year course on Integrated Design, worked in eight separate design teams on a specific case of City of the Future. The cross-pollination between departments and between faculties is also abundant and the design studies benefit from the broader relations, in terms of the joint 4TU Master programme on Construction Management and Engineering. The collaboration in teaching and supervision of master and minor students, helps to foster a collaborative culture and reach

out for joint projects through DIMI as an intermediate platform for intersectoral collaboration, interdisciplinary learning and knowledge production and its dissemination to practitioners, students and scientists.

Strengthen disciplinary and sectorial networks and collaboration

The effect of network initiatives like DIMI gives 3MD a strong position in the university. In order to collaborate and capitalise on these further targeted investments in new staff on connecting themes may use the DIMI network to engage strong mono disciplines in the 3MD Department. It can catalyse the unification of the sub-research units within 3MD to continue in this direction and build sustainable relations in the faculty, in and outside the university.
The several projects co-initiated by DIMI since 2014, has also led to a network with sectorial stakeholders. Some of them were invited for guest-lectures and others joined in a consortium developing research proposals. Some of the projects have also led to other projects which solidifies this network as a relevant link with practice.

Case study 2

Safety and damage assessment of buildings for gas-extraction induced seismicity

Assessing buildings after induced earthquakes
Earthquakes caused by gas extraction in the built environment have been a major socio-economic challenge for the Netherlands in the past years. The main concerns are safety (collapse states) and cracking in vulnerable masonry houses (lower damage states). Given the absence of natural tectonic seismicity (earthquakes), in the Netherlands had never been prepared for seismic design and evaluation of damage claims, prompting the need for research programmes involving national and international experts.

The 3MD Structural Mechanics group is a leading contributor to the research programme supporting the assessment and strengthening of masonry buildings in response to induced seismicity. Initially (2015), this programme was funded by the Nederlandse Aardolie Maatschappij (NAM), the company extracting the gas in the region. The results of this original research provided the basis for starting several other projects funded by the Ministry of Economic Affairs and Climate Policy (EZK), the Institute for Mining Damage Groningen (IMG), the Ministry of Cultural Heritage (RCE), the national coordinator for Groningen (NCG) and the Top Consortium for Knowledge and Innovation (TKI). The research programme has access to approximately EUR 10 million in funding.

Supporting governmental policy

The research is organised along three pillars: developing a safety assessment strategy, distinguishing damage caused by earthquakes from damage caused by other factors (e.g., settlement, shrinkage), and developing innovative repair and strengthening methods.

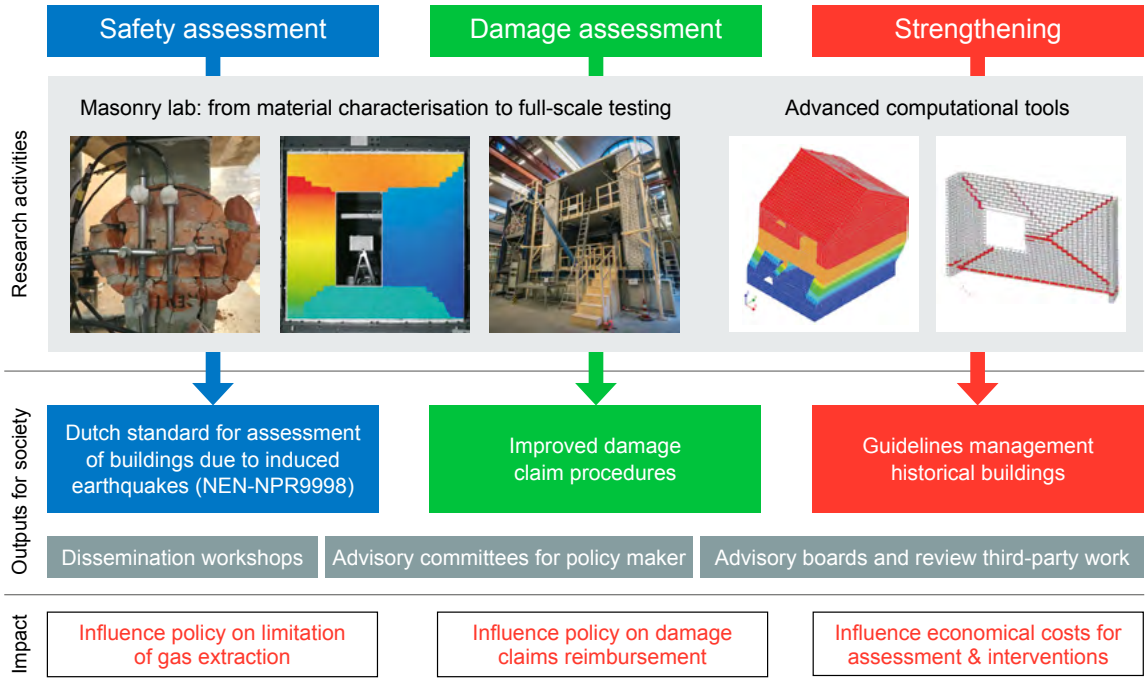
The programme developed high-quality research outputs that have met with international acclaim and resulted in new research lines related to mechanics of masonry and masonry structures, the foundation of the new Masonry lab (as part of the Macrolab/Stevinlaboratorium) and new educational content for both BSc and MSc programmes as well as for professionals (OpenCourseWare on “Introduction to Seismic Essentials in Groningen”). The successes strengthened internal collaboration within 3MD, with the ES department, and with national and seismic-specialized international partners. The scientific impact lies in validation of tiered assessment approaches against multi-scale testing (material, wall and building scale) and improved constitutive and computational models (e.g., a new masonry model in DIANA FEM software, extensive materials characterisation, improved sequentially linear and nonlinear procedures).

The programme generated major societal impact, contributing to the new Dutch standard for seismic safety assessment (NPR9998), to a new and fairer damage claim procedure, and providing guidelines for preserving historical heritage. In the process, the programme also influenced the country’s policy on gas extraction and reimbursement of damage claims and provided input for a faster and more reliable assessment strategy to reduce associated costs. To generate this impact, researchers in the group actively participated in standardisation committees, advisory boards, and served as reviewers for third-party work.

Structural resilience and sustainability

The newly established research lines are expected to expand and touch on structural resilience and sustainability in the future. This further supports the selection of resilience as the department’s new connecting theme for the next six years (see Section 10.7). The programme already managed to attract new NWA and TNO funding for research on climate-induced damage to buildings and AMS funding on resilience of urban infrastructures in 2022, both of which are expected to continue in the years to come.

Outlook of research activities, output and impact for society of the research on safety and damage assessment of buildings due to gas-extraction induced seismicity.



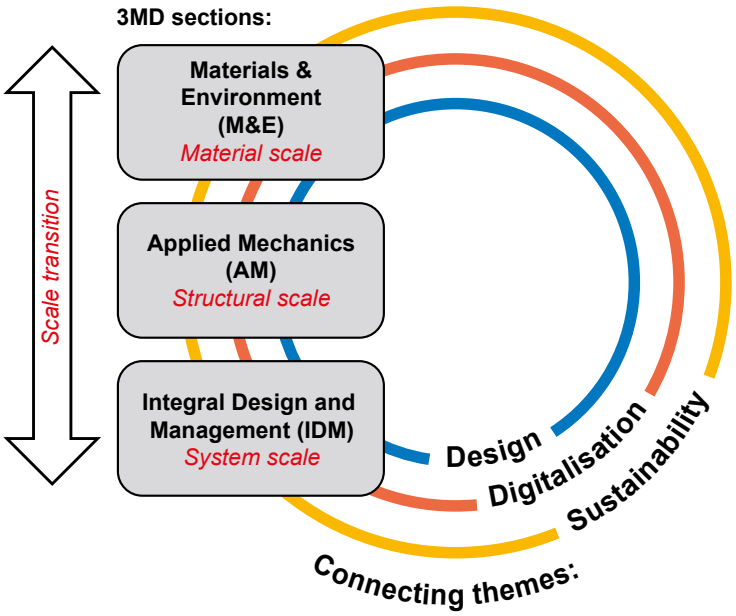
Summary

3MD focuses on design, management, mechanics and materials principles of civil infrastructures and buildings. In general, the 3MD Department aims to conduct world-class fundamental, application-oriented and societally relevant research in an open, inclusive, professional and stimulating working environment. More specifically, the 3MD Department strategically aims to:

- optimise the resilience of buildings and infrastructures, also in relation to climate change ;
- improve the sustainability of buildings and infrastructures with focus on environmental footprint and circularity performance;
- advance the transition to renewable energy systems from a materials, mechanics, management and design perspective;
- foster a technological transition to create safer buildings and infrastructures with increased performance and functionality.

These strategic aims are closely linked to the societal challenges defined in strategy of the Faculty and many of the United Nations' Sustainable Development Goals (SDGs). In the 3MD Department, research efforts in the assessment period have been focused on the societal themes:

1. Climate change: by development of durable and sustainable materials, smart technologies, and circular construction strategies in order to reduce primary raw material use, also by designing adaptive design and development of adaptive materials and structures and integral strategies and solutions.
2. Energy transition: by means of multi-scale design of (infra)structures for renewable energy systems, and by designing of energy generating and transmitting materials and structures.
3. Resource depletion: reduced material use through advanced design techniques for slender and lightweight composite structures, adaptable and re-usable materials and structures, novel (digital) manufacturing and formwork techniques, use of AI and advanced numerical modelling tools, self-healing materials for improved durability and increased life span, materials with improved recyclability, smart asset management, and circular construction models, both from a technological and an economic point of view.



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

In the assessment period 3MD invested in new junior staff on highly relevant topics, boosted the connecting theme digitalization with the establishment of the SLIMM-Lab (AI-lab), significantly invested in the Micro-Mechanical Laboratory, started the Digital Construction Lab to stimulate use of VR/AR/AR-technologies, novel imaging techniques, robotic devices and additive manufacturing, and new research lines related to mechanics of masonry materials and structures have been defined. Extra attention was paid to attract female high-potentials, but so far, with below par results. To reduce PhD-duration exceedance a number of measures were taken, a bi-annual review was organised and a buddy-system was introduced, however, also not yet leading to satisfactory results.

For the upcoming period, 3MD will focus on designing novel materials that are greener, have lower carbon emissions, use waste streams, are smarter and are made with new production techniques. 3MD will focus its research efforts on the combination of multi-scale computational mechanics techniques with state-of-the-art machine learning strategies for the design and characterisation of complex, high-performance materials and structures. Designing resilient structures and systems that can withstand climate change or natural and man-made hazards is becoming an important research theme. Furthermore, 3MD will put even more effort in improving the gender balance, emphasize more on future development of its staff in the yearly R&D meetings, and will better organise the involvement and embedding of junior staff also in national relevant networks. Furthermore, increasing visibility in and connection with national funding schemes as “Groeifonds” will be improved.