Subsurface Storage

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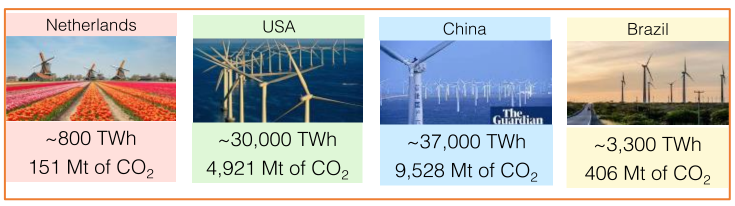
TU Delft

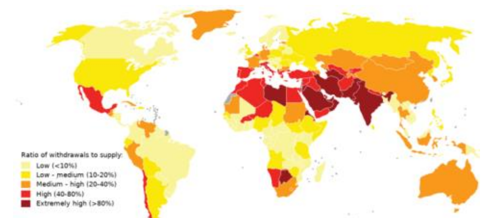
Why Subsurface Storage?

Storage technology allows to buffer oversupply to survive the period of under supply!
It is relevant to all significant topics "Water, Energy & Climate!"
Subsurface Storage is the only viable technology which allows large-scale (TWh energy, Gt Fluids)



To reach net-zero, several TWh energy must be supplied (& **stored**) & gigatons of CO_2 must be captured & stored!

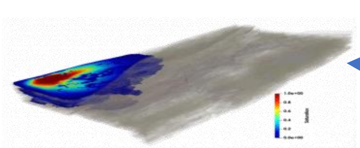
Fresh water must be captured & stored at large scale, underground!



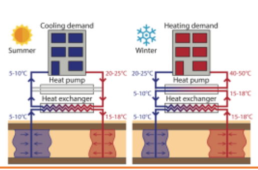
UN Water Scarcity Map! (Red: high, yellow: low)

What will you learn?

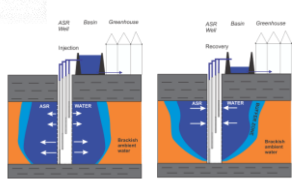
Fundamental Science & Applied Engineering Tools to store:



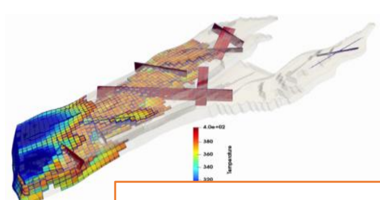
TWh hydrogen energy storage in salt caverns & porous reservoirs



Aquifer thermal energy storage!



Underground Water storage!

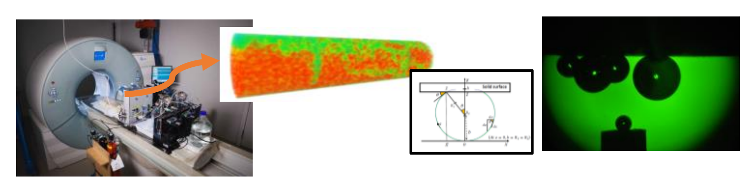


CO_2 Storage in a North Sea field!

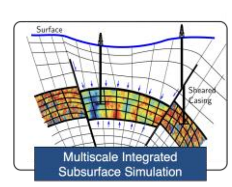
Multi-disciplines: transport in porous media, fluid-rock interactions, geoscience field development, multiscale modeling, …

Active Learning!

Discover in the Lab, Model with Pen, Simulate with Laptop, Discuss with friends, present to public!



Analyze CT-Images of hydrogen/CO_2 in real rocks!



Experience the science, Work on real challenges, find a way to make it work! Be creative! Be critical! Be Happy ☺

Model & Simulate & Analyze!

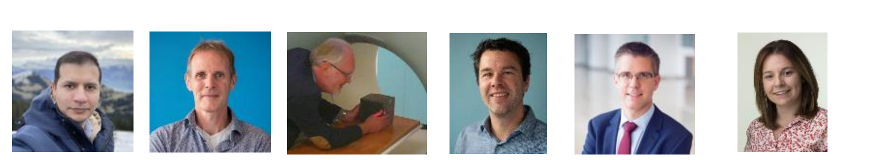
How do we assess you?

Learning objectives:

- Evaluate how earth underground resources can be used for cyclic storage of fluids and energy
- Design a conceptual framework for a given storage project considering geology & geomechanics of the rock and fluids physics
- Evaluate the performance of storage systems
- Evaluate hydro-thermo-mechanical and geochemical processes beneath the success of a storage system
- Assess the various advantages and disadvantages of subsurface storage options against each other and propose an optimal solution
- Communicate their findings clearly in an appropriate comprehensive manner for various technical and non-technical stakeholders

[50%] Portfolio of individual learning activities : Individual cumulative grade, combination of weekly assignments

[50%] Integrated module assessment: Group project, group report, Group presentation, with 1-2 pages of individual reflections



Hadi Mark Karl-Heinz Martin Sebastian Anne-Catherine

Subsurface Storage is a unique module that is relevant to all topics of Energy, Climate and Water!

Data Science and Artificial Intelligence for Engineers

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TU Delft

Course description

Data Science (DS) and **Artificial intelligence** (AI) will revolutionize all aspects of *Civil Engineering*, *Environmental Engineering* and *Applied Earth Sciences*. Our interdisciplinary module will offer students the opportunity to learn these powerful tools and apply them from the very beginning.

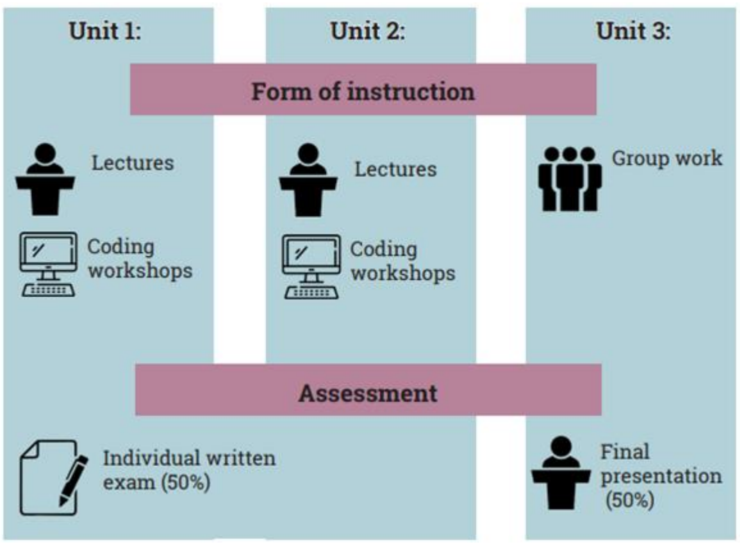
We will focus primarily on *Probabilistic Machine Learning* (Unit 1) and *Deep Learning* (Unit 2), effective approaches to deal with the uncertainty and the complexity characterizing the challenges of the interconnected natural, living and built environments.

The students will broaden their engineering understanding through collaboration with peers working on *real-world case studies*, with experts in DS/AI across various programs (Unit 3).

By the end of the module, the students will have acquired a practical and holistic understanding of DS and AI, and their applications in their fields of choice, which will be extremely valuable for the students' **future** career.

Check our **interactive book** with the content from last year!

Forms of instruction and Assessment



Instructors

<u>Responsible Instructors</u>
I. Rocha (Unit 1)
R. Taormina (Unit2)
H. Wang (Unit 3)

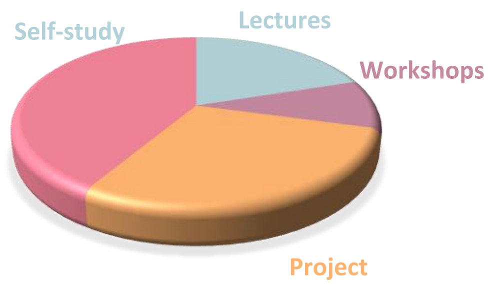
<u>Module Coordinator</u>
R. Taormina

<u>Project Instructors</u>
Experts from all the Departments

Time allocation

Around 50 hours of lectures
>80 hours for project work

Plenty of time for self-study



Project Topics

Here is the **full list** of projects presented last year.
Students can also propose their own project idea!

Best Project from Last Year

Automatic classification of plastic with YOLOv8

Monitoring of Structural Health and Geohazards

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Module description

Lifecycle engineering is currently one of the great challenges for new and existing civil and geotechnical applications. Rapid developments in sensor technology and monitoring techniques have opened many possibilities in this domain. In this module, you will be introduced to a large variety of state-of-the-art monitoring options to assess the health and integrity of civil structures, rock-, and soil masses. You will learn about the physics of structural health; how to process and interpret data for monitoring this health, and how to create and update models from the data. The module is taught using theoretical sessions on monitoring methods and data collection/processing, live coding sessions, and workshops. We conclude with case study projects in which you apply your gained knowledge to real-world monitoring problems in different domains.

Unit 1: Theory & Techniques [6EC]

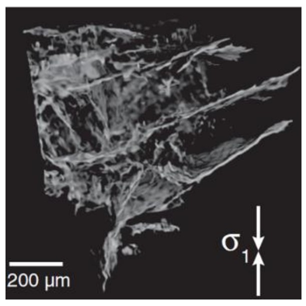
The first unit provides you with knowledge on the theory and techniques required to answer the questions 'what, when, how, why and where to monitor?'
Topics we'll cover:

- Degradation & failure mechanisms
- Relation loading ↔ materials ↔ mechanisms ↔ time- & spatial scales
- Sensors & data acquisition
- Advanced data processing (beyond MUDE)
- Inversion & prediction
- System identification & model updating
- Feature engineering, deep learning, anomaly detection & decision-making

Assessment: Written exam [30%]

Unit 2: Case studies [4EC]

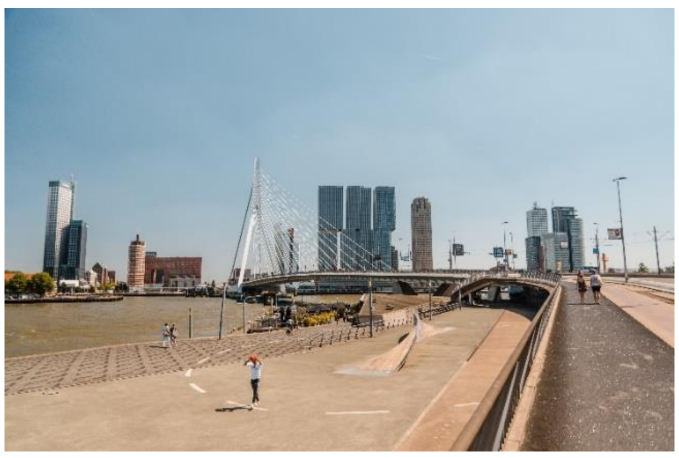
In combined groups, you'll apply your gained knowledge to 2 case studies, one in the Civil Engineering [2EC] and one in the Applied Earth Sciences domain [2EC].



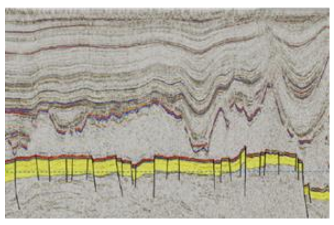
Case study examples

Civil Engineering:
Structural Health Monitoring of Bridges
You receive a data set containing accelerations and strains measured on a bridge and are asked to
1) perform operational modal analysis to identify the dynamic properties of the structure,
2) update a (given) simplified model of the bridge using the identified properties,
3) design features that can be used to monitor the global vibrational response of the bridge,
4) implement an algorithm for detecting anomalies in the response, and
5) suggest improvements to the monitoring system (locations/types of sensors, data acquisition).

Assessment: Report [35%]



Applied Earth Sciences:
Monitoring of surface deformation and changes in subsurface structures
You receive seismic reflection data, surface deformation measurements, a subsurface fault model, and seismicity data from a subsurface reservoir (e.g. from Groningen) and are asked to
1) perform an assessment of the seismicity locations,
2) perform fault slip processes modelling,
3) assess what the role of subsurface properties has on the outcomes of these analyses, including the role of possible changes in production during continuous production, and
4) devise an improved monitoring plan to improve the quantification of subsurface seismicity properties.



Assessment: Report [35%]

Hosting sections

- Dynamics of Solids and Structures
- Geoscience and Remote Sensing
- Railway Engineering
- Applied Geophysics and Petrophysics
- Pavement Engineering
- Concrete Structures
- Mechanics and Physics of Structures

Probabilistic modelling of real-world phenomena through observations and elicitation

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Content

Real-world phenomena (e.g., rainfall, earthquakes, cars crossing bridges, ocean waves) are random and **unpredictable!** How can we take this into account in our engineering research and design? In this module, you will use advanced probabilistic methods that **incorporate observations and expert opinion to support decisions** that make our **lives safer and more manageable**. The module is of the methodological type, and you will also learn how to translate theoretical knowledge into computer codes. As part of this course, you will apply the methods learned in an interdisciplinary group project around a specific theme of your choice.

Weekly schedule: Lecture – Workshop – Self-Study – Group project

Topics:
- NONSTATIONARY EXTREME VALUE ANALISYS
- DATA ASSIMILATION
- EXPERT JUDGMENT
- VINES
- NONPARAMETRIC BAYESIAN NETWORKS
- COPULAS

Team


Elisa Ragno

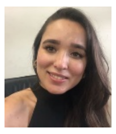

Femke Vossepoel


Max Ramgraber


Tina Nane


Oswaldo Morales Napoles

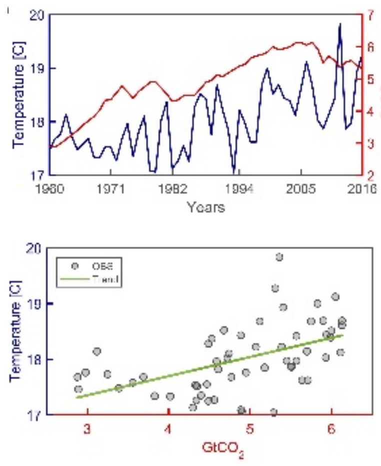

Robert Lanzafame

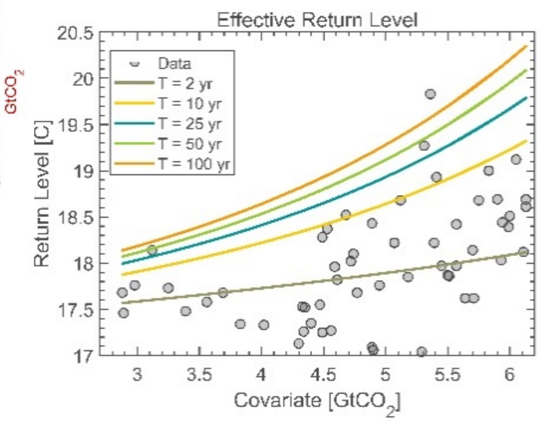

Patricia Mares Nasarre

HE
Geo Eng.
EWI

Temperature and CO_2

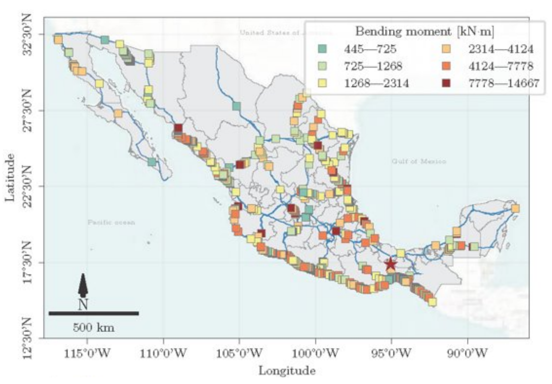
Nonstationary Extreme Value Analysis to model the distribution of annual maxima temperature for increasing level of CO_2.

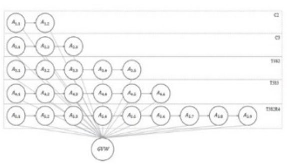




Extreme Traffic Load on Bridges

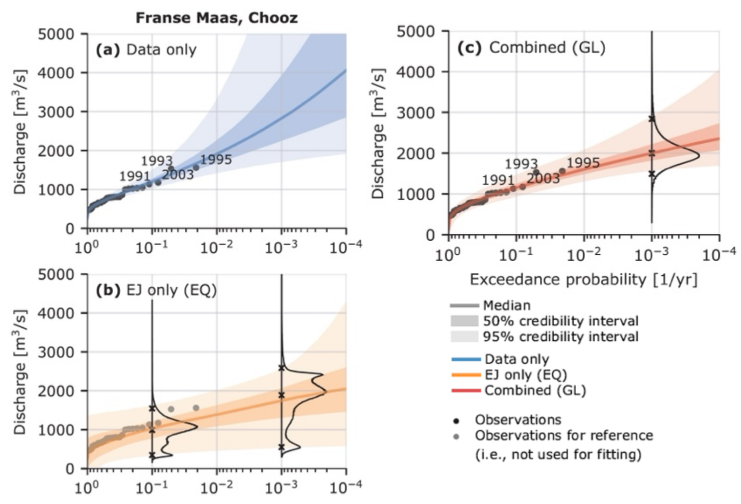
Nonparameteric Bayesian Networks to simulate axle loads crossing the bridges.z



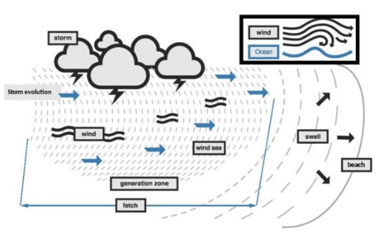


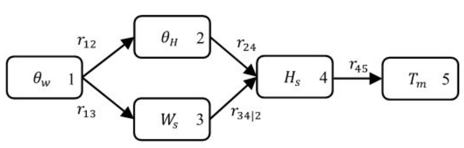
River Discharge

Expert Judgment to improve estimates of river discharge.



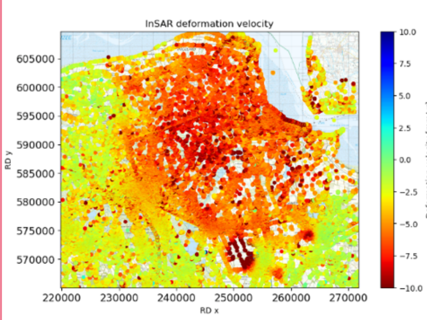
Extreme Wind and Waves

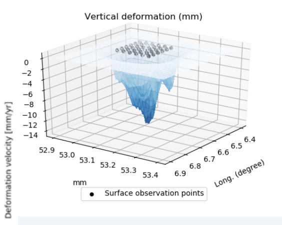


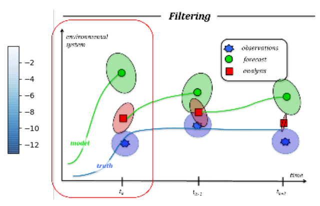


Nonparameteric Bayesian Networks to model extreme wind and waves.

Land Subsidence







InSAR **Data Assimilation** to estimate subsidence as a result of gas extraction from a reservoir.

Noise and Vibrations

Generation, Propagation and Effect on Humans and Environment

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Module Description

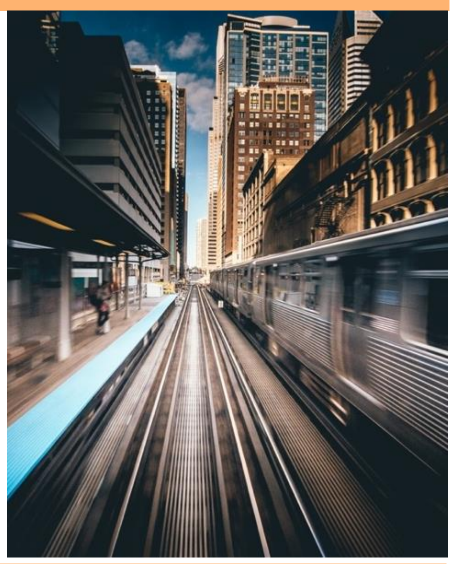
Noise refers to the unpleasant, loud, and disruptive sound that arises from structural vibrations. While urban noise and vibrations from transportation or construction works bring a negative influence on human health, underwater noise pollution (from pile driving, seismic surveys, etc.) threatens the living space of marine mammals and fish. In striving for a sustainable environment, tackling noise pollution and excessive vibrations is crucial. In this module, you will learn the fundamentals of noise and vibrations by focusing on (i) structural vibrations generating noise, (ii) propagation of waves, (iii) noise and vibrations perception by inhabitants, and (iv) noise and vibration control strategies to mitigate adverse effects on the urban and marine environments.

Environmental Impact of Offshore Renewables

Affordable and clean renewable energy remains one of the crucial global Sustainable Development Goals. However, the extraction of energy from the marine environment comes with a serious by-product; the underwater noise pollution and the vibrations of the seabed. Underwater noise can cause harm to marine mammals by interfering with their communication, feeding and navigation. During this module, you will learn how to assess the environmental impact of anthropogenic activities using state-of-the-art modelling and how to compose technically solid environmental assessment reports.

Noise and Vibrations from Railway Traffic

Noise and vibrations are significant concerns due to their impact on the passenger comfort, infrastructure durability and environment. Throughout this module you will learn the fundamentals of noise and vibrations. Additionally, you will learn how to measure noise and vibrations and analyse the resulting data.



Noise and Vibrations from Vehicles

In pavement engineering, Structural-borne noise and vibrations are caused by the interaction between the vehicle's tires and the pavement, this can lead to significant noise pollution. In this module you will learn how to model structure-media interaction and design noise mitigation strategies to reduce excessive noise and vibrations.

Unit 1: Theory	**Unit 2:** Project

Key topics

Unit 1: Theory

- Fundamentals of acoustics and vibrations
- Urban and underwater noise and vibrations
- Analysis of noise generation by structural vibrations
- Effect of noise and vibrations on humans and other species
- Noise control strategies

Unit 2: Project

- Eye on real-life applications
- Interdisciplinary groups

Form of instruction

Unit 1: Theory

- Laboratory tests
- Lectures and hands-on workshops
- Assignments and self-study

Unit 2: Project

- Laboratory tests
- Group work on project
- Feedback sessions

Assessment

Report and in-class presentation (100%)

Teaching staff

Apostolos Tsouvalas; Andrei Metrikine; Kumar Anupam; Ajay Jagadeesh; Katerina Varveri ; Alfredo Nunez Vicencio; Zhen Yang; Yaxi Peng; Andrei Faragau

Scan the QR code for more info!

Sustainable Cities

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TU Delft

Ecoengineering solutions for climate resilient and healthy cities

How sustainable is your city quarter?

Sustainability is a broad notion that includes environmental, social, and economic performance aspects. The sustainability performance of a city quarter is therefore not easy to define or quantify. In this module we are going to analyse two city quarters, a recently built one (see Figure 1) and one originating from the 1950's (see Figure 2) on the basis of a number of sustainability related indicators.

These indicators relate to and cover:

- ➔ 'Climate resilience'
- ➔ 'Climate mitigation'
- ➔ 'Circularity'
- ➔ and 'Wellbeing' performance of city quarters.

Seven specific sustainability indicators

Seven specific sustainability indicators are addressed and the performance of the two city quarters with respect to these are quantitatively assessed in this module. The seven indicators are:

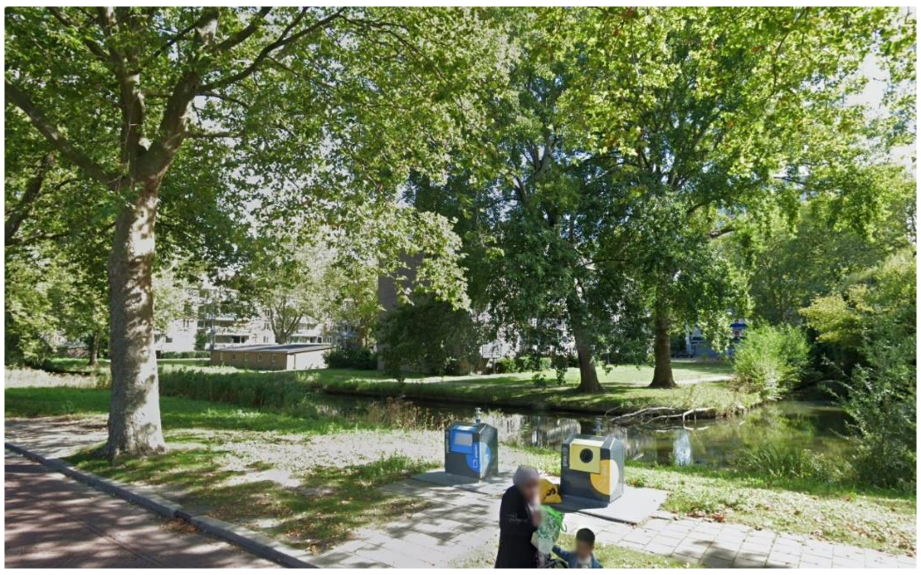
1. Quality of outdoors air, water and/or soil (including presence of litter)
2. State of maintenance and quality of present buildings and infrastructure (service life-, circularity-, energy performance)
3. Risk of heat stress occurrence (specifically in summertime)
4. Risk of flooding (specifically during intense rain showers)
5. Noise occurrence
6. Recreational- and social interaction opportunities (quantity and quality of present public spaces)
7. Quality and quantity of nature ('natural capital'): biodiversity and goods and services that nature can provide to city inhabitants

Students from different Master programs and tracks will work in multidisciplinary teams and are asked to advice and implement (design) integral nature-based sustainability improvement actions, after the current performance of the two city quarters with respect to the seven sustainability indicators have been quantitatively assessed.

An expert multidisciplinary team of teachers will inform and guide the students on theory and practice related to the seven sustainability indicators through lectures, a practical ('build and apply your own environmental sensor'), field studies and workshops. Field surveys targeting the quantification of sustainability performance of the two city blocks comprise a significant part of the student activities.

Figure 1: Schoemakerplantage

Figure 2: Wippolder



Resilient deltas *in times of climate change*

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The Challenge: Deltas as Prosperous yet Vulnerable Places

Deltas regions may be considered some of the wealthiest places in the world, drawing large populations with their rich environmental resources and strong economic potentials; they are hubs of innovation, biodiversity, industrial and agricultural productivity, and home to some of the world's fastest growing cities. Delta regions are also some of the most highly stressed areas in the world, with great competition for land and water use, and experiencing impacts from all activities occurring in the river basin. Natural characteristics of river deltas make them vulnerable to complex problems such as flooding, subsidence, cyclones and salt water intrusion. Deltas worldwide are under accelerating pressure of sea-level rise and hydrological extremes. Former high-end scenarios rapidly become thinkable futures that may push delta interventions outside common practice.

The Cross Over: Resilient Deltas

This topical cross-over deals with the societal challenge of making deltas resilient to climate change, subsidence, unprecedented economic growth and urbanisation. Future increases in sea level rise, droughts, extreme precipitation and flooding can have adverse effects on the physics and dynamics of delta's, salt intrusions and groundwater, which requires new delta interventions to be developed. The focus is on deltas globally, using the Dutch Delta as a nearby example and laboratory.

Unit 1: Physics of the Delta System

Provides you with the scientific understanding of the atmospheric, fluvial and marine processes that shape river deltas, how they respond to human interventions, and their sensitivity to climate change. Focus will be on timescales and equilibrium, changes in sediment supply, tidal amplification and salt intrusion, water quantity, quality and ecology, subsidence and sea level rise, coastal erosion, and morphological responses to sea level rise.

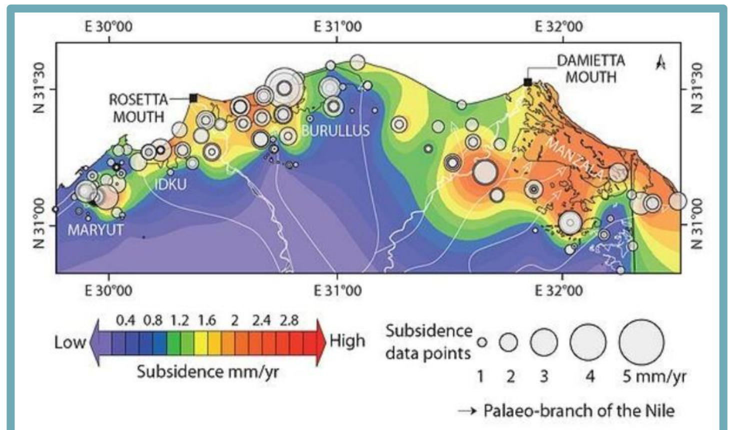
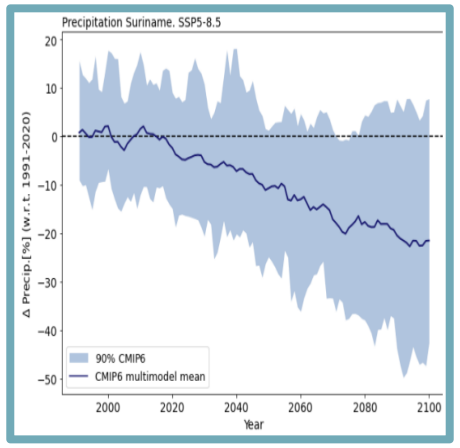


Fig. 11. Subsidence in the Nile Delta (Marriner et al., 2012).

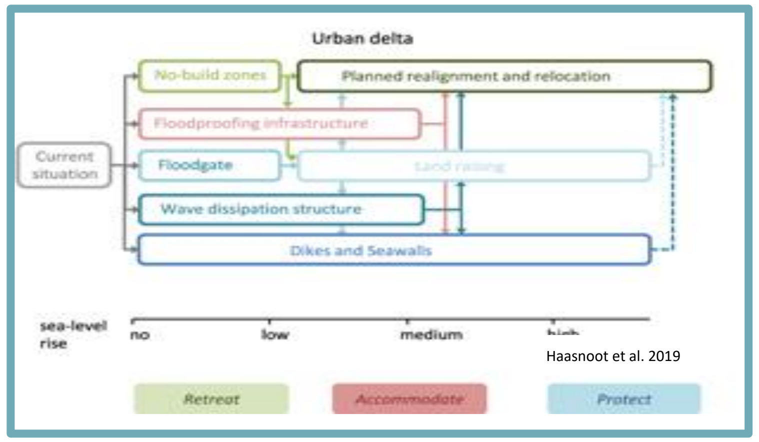
Unit 2: Climate Change and Scenarios

Provides you hands-on experience on the use of statistical and dynamical downscaling techniques and long-term observational datasets, which they need to analyse to understand the impact of natural and man-made climate change on the delta system. Focus will be on the specific climate variables: (extreme) precipitation/ droughts and sea-level rise.



Unit 3: Adaptation Pathways for Deltas

Guides you to develop pathways towards new delta technologies (flood defence and water treatment) based on climate model/data analysis using the Dynamic Adaptive Policy Pathway method, system dynamics modelling and other analytical method guided by SCRUM project management.



Staff involved

Joep Storms,
Bas van Maren, Pier Siebesma., Riccardo Riva, Caroline Katsman
and guest lecturers.

Engineering for Global Development

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What does this module aim for?

Focusing on engineering in the Global South, this module relates engineering applications (in global engineering) to a societal debate:

What is (desirable) development, a theme spanning domains, programs and tracks within the CEG Faculty, but possibly with different approaches and answers per domain.

You will learn about similarities and differences of techniques and methods from different domains. Building on the idea that engineering solutions – useful and needed as they are – are always positioned within a societal debate, students discover their own position.

You will learn how to engage their own expertise within debates with other experts and other stakeholders on issues of development, political aspects of engineering, options for interventions, contexts, etcetera.

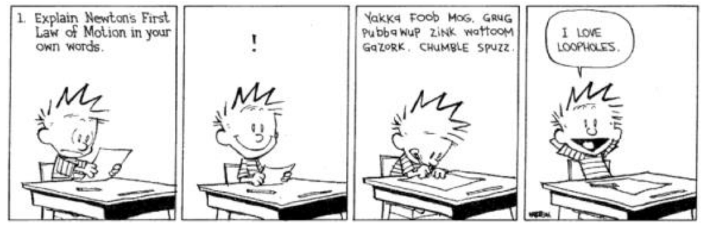
You will discover the societal and political aspects of engineering!

Grading (always good to know!)

Unit 1: Individual essay on a theme that relates to the sessions and study material (consistency of the argument, references)

Unit 2: Individual feedback essay on the team project (position in the team, reflection, writing skills)

The final grade is the average of the two grades. Each grade required to be at least 5.8.



Unit 1: Themes and debates (5 credits)

In a series of workshops, with discussions, guest lectures, design sessions, etcetera, students are introduced to themes and applications in the Global Engineering domain. The exact setup of the sessions is decided on for each study year, as themes and topics are adapted to debates as they are encountered in relevant circles.

These sessions are related to this list of key topics:

- Development theory (societal development, power relations, economic issues, globalization)
- Role of technology (engineering decisions, innovation ideas, history of technology)
- Co-creation and design interventions (participatory design, tinkering, values in design)
- Sustainable development goals (Differences and connections, development cooperation, role of states and UN institutes).

Unit 2: Topics and projects (5 credits)

Teams of 5 to 7 students work on a real-life issue, relevant to at least a number of different stakeholders (design, planning, methods, etcetera), in the Global Engineering domain.

The teams mobilize content from unit 1 in their project, in applying concepts and bringing their team work into unit 1. The projects are made available through the Delft Global network and will vary each year.

During the project activities, team members discuss the project with members of other teams, to facilitate reflecting on team results

Examples of possible projects include:

- Water provision in urban or rural settings
- Plastic pollution
- Affordable housing
- Access to energy

Please note that Unit 1 of this module is also available as elective course ENVM2106 Engineering and Development.