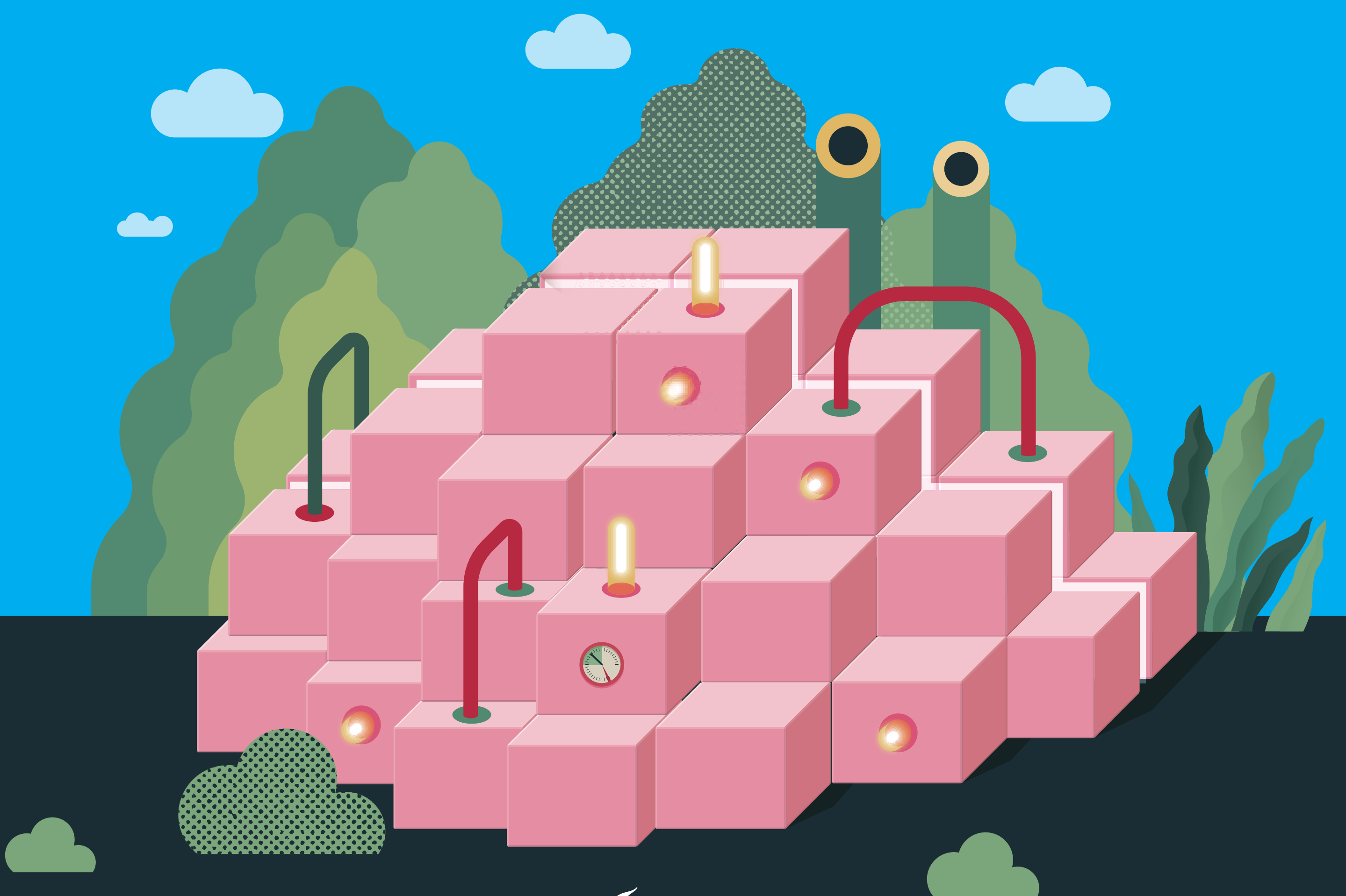
FUNDAMENT

'A treasure trove of stories'



TU Delft

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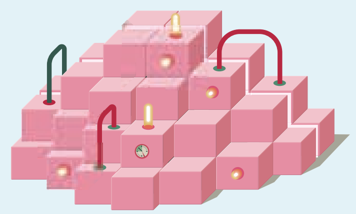


Future research

Electrical engineering

And further

PROF. DR. H.G.C. WERIJ
Dean Aerospace Engineering

FROM PRIORITY AREA TO SECTOR PLAN TO SCIENCE

Scientific research offers a treasure trove of stories. Stories about visions for the future, lots of hard work, unexpected challenges, tentative progress and sometimes breakthroughs. In short, the daily adventures of science. TU Delft continuously talks to its researchers to learn about these stories, sharing them on its Stories platform (tudelft.nl/stories). The magazine you are reading now collates sixteen stories that have one thing in common: the research they tell about, was funded through the Sector Plan funds of the Dutch government.

It's not often we put the spotlight on research stories based on the way they were funded. In fact, for the researchers themselves as much as for the outside world, it is all too easy to forget about the mechanisms that are in place to ensure the continuing success of research at our university. And this is unfortunate, as the Sector Plans have been pivotal in supporting scientific research when it was most needed.

So, allow me to take you back to 2018, when increasing student numbers and a trend towards application-oriented research were as exciting as they were stretching our core knowledge infrastructure to the limit. In the four engineering faculties (AE, 3mE, CEG and EEMCS), the number of students almost doubled between 2008 and 2018. As teaching staff numbers didn't increase to the same extent, our scientists found themselves having less and less time for research within the basic disciplines. The Dutch government, recognising this as the foundation of beta sciences asked the universities to identify the areas that needed strengthening most, and do so in national coordination. Within the engineering field, 21 of our existing priority areas were selected, spread over the three disciplines of mechanical engineering, civil engineering and electrical engineering. Individual universities and, finally, faculties translated this national prioritization into a wish list of personnel positions: the Sector Plans.

Thanks to the Sector Plans we could hire talented tenure track researchers as well as senior staff working on important topics that are at the heart of the technical sciences. For Delft, this specifically meant about 7,4 million euro, funding 17 positions at the Faculty of Mechanical, Maritime and Materials Engineering (3mE), 7 at Aerospace Engineering (AE), 12 at Civil Engineering & Geosciences (CEG) and 11 at Electrical Engineering, Mathematics and Computer Science (EEMCS). The positions cover a wide range of priority areas, from advanced materials under extreme conditions via human-robot interaction to soil mechanics. However different they may be, they are all driven by the curiosity of the scientists working on them.

Even though it is early days, and some positions are still being filled, I can already say that the Sector Plans are a resounding success. Not only in terms of bringing extraordinary talent to the university and decreasing the teaching workload, but also by strengthening coordination among the Dutch universities and by providing shared tools to provide much needed gender diversity within the engineering landscape.

In this magazine, we introduce you to all the researchers at TU Delft funded by the engineering part of the Sector Plans. Fifteen of them are currently featured on our Stories platform, and we reproduce their stories here. We also discuss the 21 priority areas of the engineering Sector Plans, and asked 4 priority area coordinators to talk about how the Sector Plans are working out in practice.

I hope you will enjoy reading this magazine!

On behalf of the four faculties at TU Delft taking part in the engineering Sector Plans,

Prof. dr. H.G.C. Werij, dean Aerospace Engineering

Reading

Delft University of Technology is committed to having significant, if not leading, impact regarding some of the most prominent challenges the world and our society are facing today. Rapid changes in technology are taking place, but in some areas the required changes are not occurring fast enough. Sometimes a revolution is needed rather than an evolution. This is why the Sector Plan funds of the Dutch government were established.

This Fundament magazine of TU Delft should be read in the framework of the Engineering part of the Sector Plans. The focus is on the technical disciplines agreed for the Engineering Sector Plan: Mechanical engineering and Aerospace, Electrical engineering and Civil engineering. Each discipline has chosen priority areas that have been aligned with other universities involved. Each story highlighted in this magazine shows both the corresponding discipline and its priority area.

TU Delft is active within two Sector Plans:

ENGINEERING | BETA

Within the framework of the Engineering part of the Sector Plans the following priority areas are reinforced within each discpline:

Mechanical engineering and Aerospace

MECHANICAL | AEROSPACE

1. Advanced materials for extreme conditions
2. Autonomous and self- learning control
3. Data-driven modelling and control
4. Distributed miniaturized instruments for Space
5. Flow dynamics for low-carbon systems
6. Human-Robot interaction
7. Multiphase flow for low-carbon systems
8. Sustainable design and manufacturing of materials
9. Turbulent flow and heat transfer

Electrical engineering

ELECTRICAL

1. Autonomous sensor systems
2. Wireless communication and sensing
3. Health and well-being
4. Microgrid components and networks
5. Digital power systems
6. Unconventional electronics and computing systems

Civil engineering

CIVIL

1. Computational mechanics of materials
2. Dynamics and monitoring of structures and infrastructural components
3. Fluid dynamics and sediment transport in human-influenced marine, inland and urban water systems
4. Fluid structure interactions for infrastructure and for nature based solutions
5. Interface and multi-scale mechanics of structures
6. Materials and environment
7. Soil mechanics

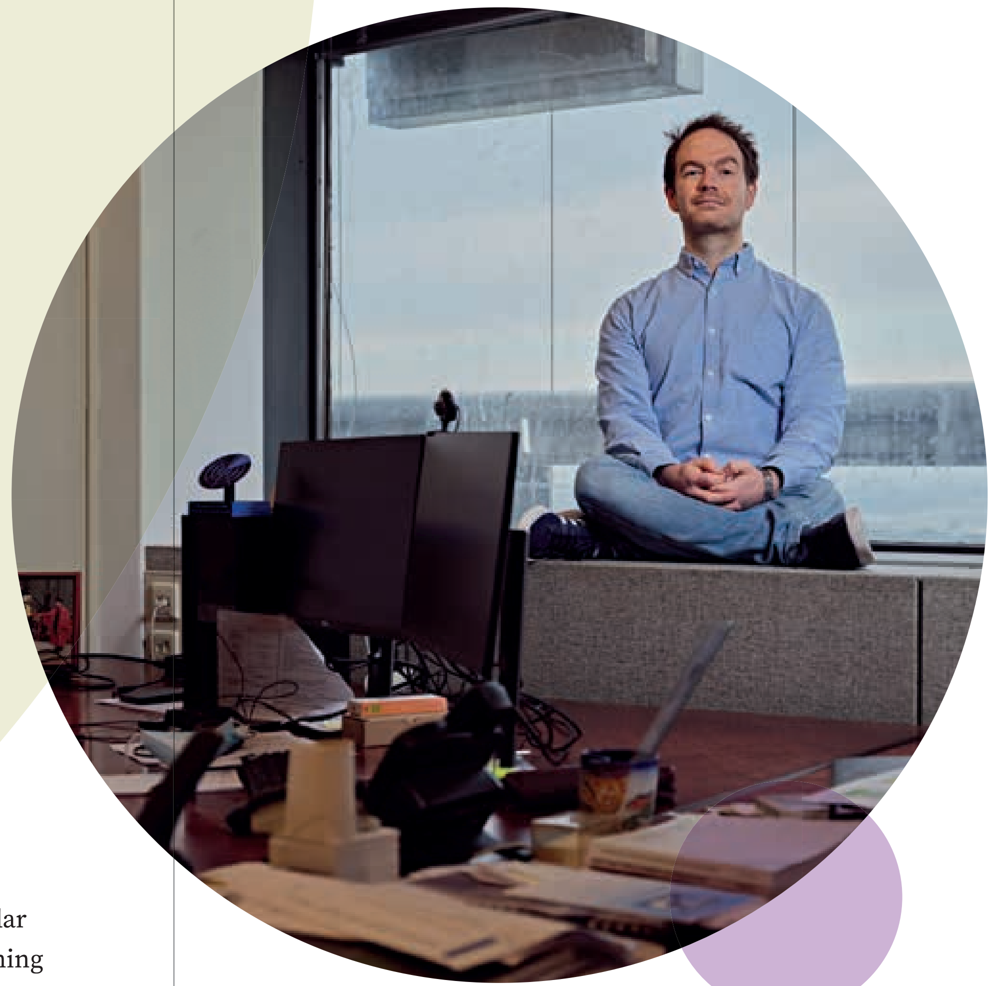
A fighter jet and your health

Radar can track both

Any kind of sensing, human or not, unveils similarities. Ice and metal may both feel cold. The sun and an apple may both appear to be red. For Francesco Fioranelli, specialised in using radar technology for the classification of objects, there is little difference between a fighter jet manoeuvring at tens of kilometres distance, or an elderly person staggering through a room.

Francesco Fioranelli is fascinated by perceiving the environment beyond the senses available to us as a human being. 'Radar is an ideal technology for distinguishing objects and their movements, without touching them,' he says. 'By bouncing electromagnetic waves of the surface of an object, we can measure its location and speed, when near or far, in rain, fog and darkness.' As an assistant professor in the Microwave Sensing, Signals and Systems group, Francesco mostly focusses on increasing the intelligence of radar – creating algorithms that use Machine Learning classification to make sense of the patterns of the radar data. Originally, he applied his knowledge for the more traditional surveillance purposes, such as ensuring safe routing for aircraft and vessels. But he was quick in realising that the continued miniaturization and cost reduction in radar technology has opened up many new opportunities.

> 'Using radar to track your health in your home environment is about raising the alarm before you need highly specialised and expensive care.'



Not such a big step

One of these opportunities is the application of radar for tracking your health in your home environment, raising the alarm before you are so unwell that you need highly specialised and expensive care. It is not such a big step from airspace surveillance as you may think. 'With some tweaking, the algorithms I used for processing radar data to identify drones at several kilometres distance are just as applicable to tracking the motion of a person in a room,' Francesco says. 'By looking at radar data, we can infer a lot of useful information about the wellbeing of a person. How that person moves and walks, for example, and in what activities he or she (no longer) engages.' This is very useful information from a medical perspective, as research has shown that walking speed, step size and general level of activity are strong indicators of your state of health. The idea is for such a radar system to be embedded into a corner of a room, or even an armchair, rather than having people carry around some measurement device that they may find cumbersome or even forget about entirely. 'In our group, we develop the tools to prove these applications in a laboratory setting,' Francesco says. 'After that, other parties are needed to continue development for real-world applications.'

A new way of looking, even for radar

Having only arrived in the Netherlands about a year ago, Francesco already wrote, and was recently awarded, an NWO Klein grant ("RAD-ART") for investigating a very novel methodology for processing radar data. 'The majority of methods in the literature try to interpret radar data as images,' he says. 'They therefore use algorithms that are based on, or at least similar to, those used for image processing. But that is not necessarily how radar works. Radar is a stream

> 'Radar is an ideal technology for distinguishing objects and their movements, without touching them.'

> ‘By analysing radar data of human motion as if it were music or speech, rather than images, we are venturing into very new territory.’

By integrating and fusing multiple types of sensors – such as optical cameras, laser ranging (lidar) and radar – autonomous cars can operate safely under any weather circumstances and darkness.

of pulses being send and received in a constant sequence.’ In his RAD-ART project, Francesco will therefore look at Artificial Intelligence techniques that are inspired by the study of sound, speech and music. The primary focus of this research is the analysis of human motion in a domestic setting – to see if with some tweaks, these techniques will help in training a radar system to understand the large variety in human movements. But the same algorithms can also be used for other applications such as surveillance – think of a drone hovering somewhere and then suddenly accelerating towards an airport. Francesco: ‘We are venturing into very new territory. It could well be that in four years we conclude that it doesn’t work.’

A tree won’t cross the road

A perhaps somewhat better-known, but still quite new application of radar is its use in autonomous cars. By integrating and fusing multiple types of sensors – such as optical cameras, laser ranging (lidar) and radar – autonomous cars can operate safely under any weather circumstances and darkness. Francesco and his colleagues work on the interpretation of these radar signals to get an awareness of the surroundings. Again, it is about object recognition. ‘These radar data look like blobs,’ Francesco says. ‘We want to, for example, be able to say if these blobs represent a big truck in the opposite lane or perhaps a car using your lane to overtake another car.

Likewise, the car needs to be able to distinguish a tree or lamppost next to the road from a person, as the latter may decide to cross the road at any moment.’ One way the researchers try to improve this situational awareness is by training a radar system using data obtained with optical cameras. ‘We are working towards a laboratory setup where we have a camera and various radar boards looking at the same scene, collecting data simultaneously,’ Francesco says. ‘The department is also considering buying some target simulators. Rather than having to go through the cumbersome process of building real-life scenarios, these devices can simulate how radar echoes will look for a given radar and several targets, speeding up data-acquisition tremendously.’

Radar to the rescue

Francesco is convinced that his research can have a positive impact on the world, but also clear about radar not being the answer to everything. ‘Radar may never be able to beat high-quality medical devices,’ he says, ‘but it may offer a cheaper and less invasive solution, allowing a person’s health to be monitored outside of a hospital setting.’ It will take some years for radar to make it into our homes and cars, and those of our ageing parents. Until then, when in traffic, you may at times still have to rely on your fighter jet-inspired evasive manoeuvres.

FRANCESCO FIORANELLI
Assistant Professor Microwave Sensing, Signals and Systems (MS3)

> ‘We want to raise the situational awareness of car radar by training these systems using data obtained with optical cameras.’

RESEARCH FOCUS: ROBOT NAVIGATION NEAR HUMANS

HIT THE ROADS SAFELY WITH AUTONOMOUS VEHICLES

When the time comes for autonomous cars to hit the roads, they'll have to take other road users into account. For example, they'll need to stop when a cyclist abruptly turns. Laura Ferranti is studying how this can be best achieved. Even when roads are packed with traffic.

Imagine, you're driving your car through the centre of Delft, guiding the vehicle along the picturesque canal-side houses and over a quaint bridge. Before you turn off, two cyclists speed by at the last moment. After they've passed by and you want to accelerate, a father with a pram quickly crosses the road just in front of you. This isn't an unusual scene in the busy centres of Dutch cities. Road users are used to it by now.

'But these situations are extremely difficult for technology to figure out,' says Laura Ferranti. She's a researcher at the Department of Cognitive Robotics at TU Delft's 3mE Faculty. 'How does a car know exactly when someone is about to cross, and how do you make sure you notice all those two-wheelers speeding by? These are obviously things we need to sort out if we want to make a car that's nearly or completely autonomous. At the same time, you don't want the vehicle to remain stationary all the time just because it's afraid to move in any direction whatsoever as a result of all the other road users.'

You're trying to predict something that's quite unpredictable

'A cyclist who looks over his shoulder a few times and then sticks out his hand is easy to notice. But someone who turns the handlebars with no warning isn't. Still, the car has to take both into account.'

‘They estimate whether a pedestrian will cross a road or a cyclist will make a turn and precisely when. They do this using sensors, such as cameras and GPS that tell the vehicle where these pedestrians and cyclists are. And radar plays its part too, as it makes a 360-degree image of the surroundings. We use that information to estimate the car’s possibilities. We want to determine which routes the car can take to safely reach its destination.’

Robots and humans working together

That’s why Ferranti is working on solutions with colleagues from Dariu Gavrila and Javier Alonso-Mora’s team. They’re developing technology that will allow vehicles to detect everything around them and know when they can and cannot accelerate. So it’s a technology of the future. You could view this kind of autonomous car as a driving robot. In recent decades, robots were usually hidden behind the high walls of factories, where they assembled electronics, for example. ‘But the new generation really must work together with humans. It won’t be long before we see these robots on our streets.’

This means that vehicles will be constantly predicting which route is the safest to follow. ‘They estimate whether a pedestrian will cross a road or a cyclist will make a turn and precisely when. They do this using sensors, such as cameras and GPS that tell the vehicle where these pedestrians and cyclists are. And radar plays its part too, as it makes a 360-degree image of the surroundings. We use that information to estimate the car’s possibilities. We want to determine which routes the car can take to safely reach its destination.’

To achieve this, you to have an accurate idea of what people are going to do and how to process this information in order to safely continue driving. The car’s system interprets this, as it were, by reading body language, posture, movements and the direction a person is going in. A cyclist who looks over his shoulder a few times and then sticks out his hand is easy to notice. But someone who turns the handlebars with no warning isn’t. Still, the car has to take both into account.

Predicting the unpredictable

‘Ultimately, several (partly) autonomous vehicles will share this information with each other in the future,’ Ferranti says. In addition to cars, it will also include ships and drones delivering packages. The idea is to make things safer by sharing information. Another vehicle may have a better view of road users, which will help your car make the most accurate estimation possible. ‘The vehicles also communicate where they are going. So if you make a turn, other road users will receive that information as well. So you’re helping each other.’ Vehicles will therefore continuously communicate with each other. This must be done in a safe and responsible manner,

LAURA FERRANTI
Assistant Professor at the department of Cognitive Robotics (CoR).

says Ferranti. ‘As researchers, we ensure that vehicles will drive, sail and fly safely in the future. But it’s also important to think about privacy. A great deal of data is being collected, and we take images of other road users. You have to make sure that everything is well protected. We’re already thinking about this as well.’

This technology is still developing, so the autonomous car is still a vision of the future. The fact that Ferranti is working on the traffic of the future is not entirely coincidental. She used to be fascinated by the roads in Rome, where she was born and raised. ‘The traffic criss-crosses all over the place there. Cars switch lanes at a moment’s notice, scooters zigzag in between everything, and then there are the pedestrians who cross whenever they please. It’s a nightmare for traffic experts. At the same time, it’s also very interesting. Because in the future, autonomous cars are going to have to learn to read and understand these kinds of situations too. I often think about this during my research.’

This practical approach characterises Ferranti’s method as a scientist. She started out as a researcher who liked to focus on theory. ‘I enjoyed working on abstract problems and made many calculations. Now I focus on realistic and practical problems: how robots can safely move among humans. Suddenly, very different uncertainties come into play. It’s much more complex. That’s why I found it a bit scary at first. But that has changed in the meantime. Now, working on real problems and trying to solve them appeals to me. But the field of research remains exciting, because you’re trying to predict something that’s quite unpredictable.’

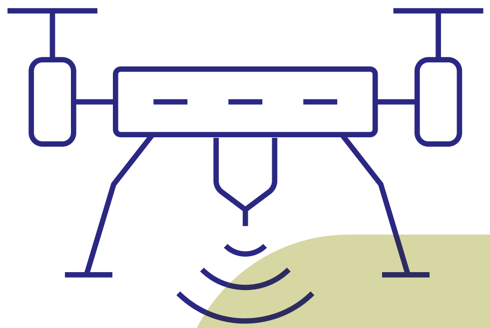
Autonomous robots protect the lives of emergency services in disasters

Search and rescue robots play an important role in rescue missions following disasters. Anahita Jamshidnejad is trying to make these robots even more intelligent so that they can make decisions autonomously in complex situations, thereby relieving rescue workers of life-threatening tasks and making rescue operations more efficient.

Every second counts in the initial response to disasters such as fires and earthquakes. If help comes too late, or if rescue workers assess the situation incorrectly, this may result in many victims. In recent years robots, including drones, have been increasingly used to assist in search and rescue missions, says Anahita Jamshidnejad, assistent professor at the Control and Operations department. 'A drone is a great tool for assessing situations, damages or risks in a building or area. In particular when the situation is unknown and may pose a high risk to the lives of rescue workers, for example due to poor sight or the risk of explosion and collapse. Sending in a search and rescue robot first enables us to limit risks since robots can collect information even from places that are dangerous or inaccessible to humans.'

Major fire as motivation

In early 2017, Jamshidnejad experienced at close hand the importance of efficient rescue efforts. 'Together with my family, we were watching a live TV broadcast of a rescue operation in a burning landmark building in my hometown Teheran. The TV reporter had just announced that the building had been evacuated from inhabitants by firefighters, who were still inside trying to extinguish the fire. Suddenly the building collapsed before our eyes, which led to the death of over thirty rescue workers. I believe if robots had been used to make a risk assessment first, this tragic ending could have changed for a happy one. During my PhD programme in System and Control Engineering, I had already done research on autonomy of systems via artificial intelligence and model-based control, although my research was mainly theoretical. The fire in Teheran motivated me to start using my expertise for practical search and rescue applications.'



> 'I believe if robots had been used to make a risk assessment first, this tragic ending could have changed for a happy one.'

Search and rescue robots should become autonomous

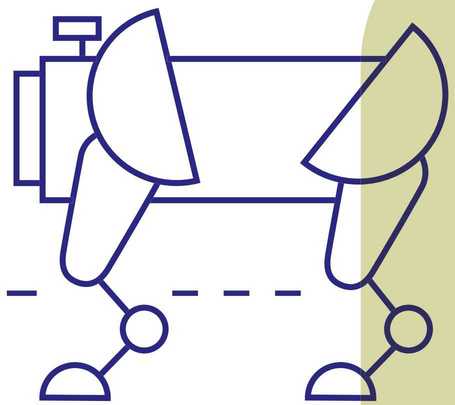
One of the reasons that search and rescue robots are not always used is that they cannot operate fully autonomously, says Jamshidnejad. 'Drones do not yet have fully autonomous decision-making capabilities. Human assistance is still needed to operate the drones and to determine what actions they should perform. You can pre-programme them with information about a building or area, but during a disaster the situation changes. Uncertainties such as blockages from collapsed walls or unpredicted spread of fire mean that the initial floor plans or maps of the area may no longer be accurate. This is particularly where search and rescue robots can make a difference: they can independently go into the unknown area, plan a mission and start to search and assess the new situation. Then they can transfer the most important information to rescue workers to determine the places they need to go to or should avoid.'

Mathematical decision-making and AI: breakthrough in next gen robots

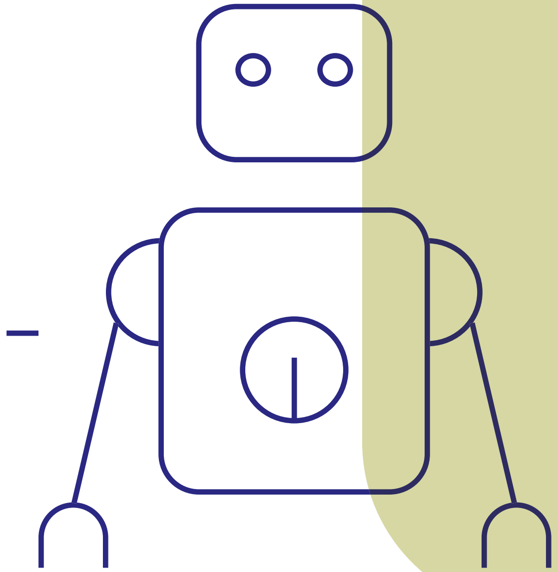
At the time of the fire in Teheran, Jamshidnejad was finishing the last months of her PhD studies. After obtaining her PhD, she decided to follow up a postdoctoral research position at the Institute for Dynamic Systems and Control at ETH Zurich. In February 2019, she returned to the Netherlands to continue her research in Delft. 'I had already done my PhD at TU Delft, so I had an extensive network of researchers in the Systems, Control & Simulation research groups. Besides this, at TU Delft there is extensive expertise in the field of artificial intelligence (AI), which dovetails well with my own theoretical background in mathematical decision making and modelling. One of the topics I am currently working on is systematic incorporation of uncertainties in mathematical and model-based decision making: How can a robot or a drone operate autonomously when confronted by various random, vague and unpredictable situations? We also want drones to use a combination of optimization and AI to learn from these situations to recognise danger and locate victims or hazards.'

Minimizing use of power

'Search and rescue robots analyze and transfer the data they gather to the rescue team outside the disaster scene in real time', continues Jamshidnejad. 'It is crucial that no important information is lost if a drone suddenly becomes out of function'. Most drones are fitted with a camera but in extreme circumstances the images



ANAHITA JAMSHIDNEJAD
Assistant Professor Mathematical Decision Making



'People with autism find it difficult to make contact with others. It is often easier for them to communicate with social robots.'

they send may not be useful, for example due to darkness or smoke. Or sometimes a camera may fail. Therefore, often several robots and drones are deployed at once. One or a few of them receive the most important data of the team when one is lost. 'It takes a lot of power to process all the data, so we need to develop an optimal approach that minimizes the use of power, as well as the mission time'.

Next: Collaboration with fire services

Jamshidnejad plans to use model-based and knowledge-based control methods based on the expertise of experienced rescue workers, such as the Dutch fire departments. 'Fire brigades know all the aspects associated with a disaster and the dangers involved. We can use their expertise and information on disasters and emergency situations to simulate scenarios that are similar to real-life search and rescue missions in the lab. This way we can perform experiments to assess and improve the performance of our robots. Moreover, in the end our robots should collaborate and communicate with real fire fighters.

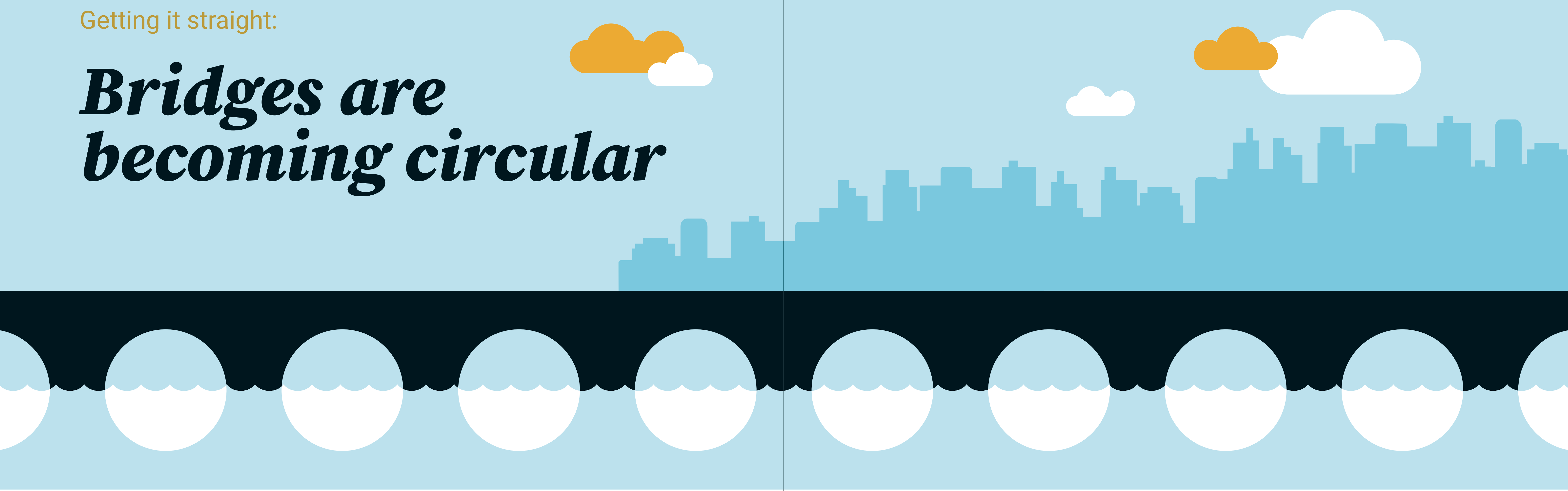
Therefore, close collaborations and interactions with fire departments from the very first stages of implementations of the project are necessary. Another important partner in this research is Thales, a company that specialises in drone technology, among other aerospace applications. Thales is helping us with the further development of well-functioning search and rescue robots.'

More applications for autonomous robots

'Improving the autonomy and efficiency of decision making by robots is not only useful in search and rescue', says Jamshidnejad. There are also valuable healthcare applications, such as therapeutic aids for people with autism or dementia. Jamshidnejad: 'People with autism find it difficult to make contact with others. It is often easier for them to communicate with social robots, in part because of the robot's predictability and lack of emotions. For the first time, we are introducing social drones that engage in dance therapy. We want to further improve robots, so that when they are in interaction with people with autism or dementia they can assess situations independently and act based on a personalized and creative plan. In summary, my research has a wide range of applications. I think it's really great that I can now use my theoretical background to help solving real-life problems.'

Getting it straight:

Bridges are becoming circular



A large number of bridges in the Netherlands are scheduled for large-scale maintenance work or replacement. In order to minimise the effect on the environment and bring down costs researcher Wenjun Cao is working on a model to assess the potential for circularity of these bridges. This will help the Netherlands to achieve its aim of a fully Circular Economy (CE) by 2050.

Railway bridges, drawbridges, fly-overs, sluice bridges: the Netherlands leaves the rest of the world standing when it comes to the number of bridges per square kilometre. The exact number is not known but the water authorities alone are managing over a thousand. Many of the bridges are approaching the end of their life cycle, says Wenjun Cao, assistant professor Engineering Structures at CEG. 'Much of the Dutch infrastructure dates from the post-World War Two period, as is the case in many other Western European countries. A concrete or steel structure has a life span of at least 50 -100 years. But traffic has intensified over the years and maintenance work has to be carried more frequently. Quite a few bridges will have to be partly or entirely replaced in the next couple of years.'

The importance of good infrastructure

Cao became fascinated by bridges when she was a little girl living in China. 'I grew up in a small city in the north of Shanghai. In order to get to the big city we would have to cross the Yangtze river by ferry. In 2008, with the opening of Sutong Bridge, the transportation time between cities has been cut down from three hours to one hour. That's when I first understood the importance of good infrastructure and the value of bridges. It prompted me to study Civil Engineering in China. Following my graduation, I went on to work as a bridge engineer for five years and did a PhD in Singapore.'

Circular champion

Cao came to Delft in June 2020. 'I wanted to do more research into the potential for circularity in civil infrastructures. The replacement brief and the developments in circular building make the Netherlands an interesting country. However, reuse of infrastructure has remained relatively underresearched. Bits of bridges or roads are being recycled here and there but it's not happening in a very efficient way. What is needed is a comprehensive approach. It is my aim to set up a framework in which circularity is integrated into the design, construction, operation, maintenance and dismantling of infrastructure, starting with bridges.'

Advantages for the Netherlands

Circular building has many advantages, Cao says. 'Less production of steel and concrete will lower CO_2 emissions. Recycling the way it is done now is energy intensive, particularly when it comes to separating the materials of a bridge component, grinding it down and using it to produce something new. We can skip that step if the components have the potential to be used in a new construction, for example.

'It is my aim to set up a framework in which circularity is integrated into the design, construction, operation, maintenance and dismantling of infrastructure.'

'Every bridge will be given a circularity label, similar to the energy labels for homes. According to the label a bridge or a component is fit for repair, reuse, rebuild or recycling.'

Efficient reuse of bridges can help the Netherlands achieve climate and circular economy goals. And what's more, it pays. According to my calculations, assuming the average cost saving through circular strategies is 5% - 15%, with every 1% of the road sector adopting the recommended strategy, the potential market we are dealing with is worth $15- 53 billion from 2016 to 2040. The Netherlands could become a circular building pioneer and export its knowledge to other countries such as Germany and France which are facing similar infrastructure challenges.'

Circularity label

Cao's research is focused on the circularity potential of bridges. That means she will be studying the current state of the bridges, the materials used to build them and the environment in which they are situated. Cao: 'Based on this information we can estimate which parts of the bridge can be reused or repaired and how to go about it. Every bridge will be given a circularity label, similar to the energy labels for homes. Depending on the assessment, a bridge or a component can be labelled fit for repair, reuse, rebuild or recycling.'

Reuse of existing infrastructure

Changing the purpose of a structure is a particularly revolutionary approach, Cao says. 'It has been happening a lot with buildings lately. An old factory is turned into a restaurant, for instance. The same can be done with infrastructure. A bridge that is no longer fit to carry heavy traffic can be repurposed as a pedestrian bridge. Rebuild, or using components of a bridge that has become superfluous to build another in the area, is a relatively new phenomenon too. In that case it is important to check if the structural behaviors of the components are suited to the conditions surrounding the new bridge. If metal components are used in a bridge standing in water with a higher salt content they had better be corrosion proof.'

Artificial Intelligence

The big challenge is to chart the thousands of bridges in the Netherlands. To study every single bridge in detail in the traditional way is neither viable nor necessary, Cao says. 'For the collection of data we will be turning to AI. Sensors and drones can help us study bridges in great detail. We then combine these data with the information we have on the age of the bridge, the structural type and material behaviour. Based on the data analysis every bridge is then provided with its own circularity label. So I will be working very closely with AI specialists.'

Information sharing platform

Cao's aim is to develop a platform for (local) authorities and businesses to share information about ways to include bridges in the Circular Economy. Cao: 'In order to achieve optimal circularity cooperation throughout the chain is crucial. Smart design can help to efficiently take apart components and reuse the materials of bridges. With smart design and modular building, you can dismantle a bridge as easily as if it were made of Lego. And not just bridges but other types of infrastructure as well, such as roads and railways. That shows the potential of this research.'

'The big challenge is to chart the circularity potential of the thousands of bridges of the Netherlands.'

WENJUN CAO
Assistant Professor Engineering Structures at CEG

L.T.R: HANS HELLENDOORN, LINA SARRO, GUIDO DE CROON AND BERT SLUYS

'WE SHOULD HAVE DONE THIS EARLIER'

For TU Delft, the engineering Sector Plans represent the reinforcement of 21 priority areas spread across four faculties. How do four leaders in these priority areas, one from each faculty, look back on the implementation of the plans thus far? The day after the announcement of a new coronavirus lockdown, professor Lina Sarro (EEMCS), professor Bert Sluys (CEG), professor Guido de Croon (AE) and professor Hans Hellendoorn (3mE) met digitally to discuss this issue.

To begin with, what exactly do the Sector Plans entail again?

Sluys: The idea is to highlight certain fields of study which have been somewhat overlooked in recent years because of their more fundamental component. For us, this means a significant strengthening of staff. A unique opportunity and an extremely important contribution to education and research, also in the long term. Our groups have been able to attract top scientific talents who would otherwise not have come.

De Croon: The same applies to us. Aviation is facing major challenges, and that's also putting considerable pressure on our education. Issues such as sustainable aviation and autonomous drones are booming; society urgently needs engineers trained in these fields. The Sector Plans offer scope to strengthen these disciplines, including education. It's going to have a considerable impact, I'm convinced of that.

But these funds didn't come without strings attached. How was that received?

Hellendoorn: As a faculty, we were forced to think about our focus areas. That's not something we would have done on our own volition, but it was extremely helpful.

'AVIATION IS FACING MAJOR CHALLENGES, AND THAT'S ALSO PUTTING CONSIDERABLE PRESSURE ON OUR EDUCATION'

Why?

Hellendoorn: Mechanical engineering is an old discipline. Millions of years ago, people were already making tools. Since then, the discipline has grown in all kinds of ways. The Sector Plans forced us to ask ourselves: who does what and why?

GUIDO DE CROON
Professor 'Bio-inspired Micro Air Vehicles' (faculty of AE)

Sluys: This coordination has also taken place nationally. We sat down with our colleagues from Twente and Eindhoven, which was a positive step. We have to continue working together, even though the positions have already been allocated and are being filled.

There were also requirements regarding the distribution of positions to males and females.
Hellendoorn: The fact that a third of the positions should be occupied by women was a tough requirement. That's been a tremendous help. In fact, I would recommend it to everyone.

'FOCUSING ON SOMETHING ISN'T THE SAME AS MAKING IT COMPULSORY.'

Surely, the sectoral plans weren't so unusual in that respect? Focusing on gender balance is pretty much universal now, isn't it?
Sarro: Focusing on something isn't the same as making it compulsory.

Hellendoorn: We're a somewhat older faculty, and we still had groups that didn't employ a single female researcher. I think that women are inherently at a bit of a disadvantage there. But these groups had no choice. I have seen with my own eyes how the atmosphere there has changed. We've brought in excellent women, who immediately won a Veni grant from NWO.

Sarro: But that's how it should always be.

Hellendoorn: That's true. But if this helps...

De Croon: We didn't hire our new female staff members because they're women. They were without doubt the best candidates.

Hellendoorn: What is the 'best' candidate?

De Croon: That's not easy to define. You have to look at expertise, research results and teaching skills, for example. There are many factors to consider. It's not an objective calculation that a computer could make as well.

Hellendoorn: Ultimately, it's decided by a committee that has a certain idea of what the 'best' candidate is. And sometimes you have to force a committee to briefly renounce their traditional way of thinking.

How did the search to fill the Sector Plan positions go?
Hellendoorn: It wasn't always easy. For example, we had to fill a position for professor. That's extremely tricky in our field. We searched endlessly and finally hired a promising associate professor.

Sluys: We actively searched and even enlisted a recruitment agency. But then you find people who have a different motivation than the candidates who are looking for you.

Sarro: There's a strong competition for good candidates. And sometimes you come across a fantastic candidate who doesn't fit the profile you have in mind.

Hellendoorn: Sometimes you have to use a hammer to make the piece of the puzzle fit.

LINA SARRO
Professor Electronic Components, Technology and Materials (ECTM) at the department of Microelectronics (faculty of EEMCS)

'IT'S IMPORTANT FOR TENURE TRACK RESEARCHERS TO START THEIR RESEARCH WORK AS SOON AS POSSIBLE.'

BERT SLUYS
Professor Computational Mechanics (faculty of CEG)

Sarro: It's a human process, and the larger result is what counts: enhancing research and teaching.

Is this enhancement noticeable yet?
Hellendoorn: It's already having a positive effect for us. Our new staff members are already teaching and supervising students, which immediately reduces the pressure on the rest of the staff. We can now spread our 100 graduates across 21 instead of 17 staff members.

Sarro: The pandemic hasn't made it any easier for new researchers to start their work. Some only know Delft through Zoom. So I don't expect to see the effects for another year.

De Croon: On the one hand, the workload has been reduced, but on the other hand, I've spent a great deal of time finding candidates for these positions. So for me it's been a little bit busier. But I love doing it, because I know that in time we'll really benefit.

Sluys: It's important for tenure track researchers to start their research work as soon as possible. Teaching gradually comes into play after that. In terms of teaching, I expect a lot from them: they've been partly selected for their teaching qualities.

Sarro: These new colleagues really like teaching too! That's why they chose to work at a university and not a company. They're looking to interact with students. We have to be careful not to put too much on their plates too quickly.

Has the foundation of the engineering sciences been sufficiently reinforced now?
Hellendoorn: I don't want to sound greedy, but we're not there yet. Our student-staff ratio was 40:1. Thanks to the Sector Plans, that's been reduced to 34:1, but that's still far from ideal. We've grown tremendously in recent years; this is overdue maintenance.

De Croon: Students studying engineering need to be closely supervised, and complex equipment has to be set up first.

Sarro: I would like to emphasise this: engineering studies are all about the long term. That's why I see the engineering Sector Plan as a kind of appreciation and recognition by the government that we won't get anywhere with proper funding.

Hellendoorn: After the previous economic crisis, there was an enormous increase in the number of students in engineering studies. As a result of COVID-19, we're once again in the middle of a crisis. Who knows, it's conceivable that many more students will opt for engineering again.

Sarro: That's why I believe we should have developed the Sector Plans sooner and in more detail.

PROF. DR. IR. HANS HELLENDOORN
Department Head Cognitive Robotics (faculty of 3mE)

'SOMETIMES YOU HAVE TO USE A HAMMER TO MAKE THE PIECE OF THE PUZZLE FIT.'

FUTURE RESEARCH

The spotlight in this Fundament magazine is on 15 researchers who have been working on their research at TU Delft for some time. But positions are still being filled and so new researchers are starting each month. Who are our newest talents and what will they be focussing on?

ALEKSANDRA LEKIĆ
DIGITAL POWER SYSTEMS

'I will conduct research on nonlinear controlling methods for hybrid power systems. The hybrid power system presents an AC power system interconnected with a High Voltage DC-based power system through power converters. The hybrid power system is the system of the future. My ongoing research is to design new controls and test the system's stability after the application of the controlling method.'

'The outcome of my research will contribute to the decarbonization of the power system. Application of new control methods into a hybrid power system will ensure its stability, together with faster convergence and recovery from faults. Research results will include the implementation of the multi-vendor control for hybrid power.'

SHOSHAN ABRAHAMI
SUSTAINABLE DESIGN AND MANUFACTURING OF MATERIALS

'I will conduct research on the recycling of hybrid and complex materials. This will include developing recycling routes for existing structures and materials that are currently difficult to recycle, as well as collaborating with colleagues who are designing and building future materials on 'design for recyclability'. Initially, I will investigate the recycling of high-performance thermoset composites that are used for structural components in aviation and transport and looking into the reuse and repurposing options for wind turbine blades. In the near future, I plan to expand to different types of material combinations, including batteries, waste electrical and electronic equipment, and multilayer packaging films.'

'The outcome of my research will contribute to society and the environment by improving the circularity and sustainability of materials. This is a difficult task, as materials and structures are becoming more multi-functional, requiring complex combinations of materials and elements, but I am confident that we will be able to make a positive shift, as this issue is receiving more and more attention from society, as well as government and industry.'

KSANDER DE WINKEL
HUMAN-ROBOT INTERACTION

'I will conduct research on motion sickness. According to the most prominent theory, motion sickness results from something called sensory conflict. This conflict represents a discrepancy between motion that our senses signal and motions we expect based on an internal predictive model. However, it is uncertain what this conflict really is. Present models represent it in different ways, and they are only partially successful in actually predicting motion sickness. In my research, I hope to improve our understanding of what motion sickness is by finding ways to detect early signals of motion sickness; by exploring new modeling techniques; and by accounting for individual differences in susceptibility.'

'The outcome of my research will enhance the comfort of traveling, in particular in the context of automated vehicles. By maximising comfort and minimising the chances of motion sickness, we will make sure that we can use the full potential of this new technology: freeing up time to engage in activities other than driving, improving fuel economy and reducing the risk of accidents. This will benefit not only the individual, but society as a whole.'

SID KUMAR
SUSTAINABLE DESIGN AND MANUFACTURING OF MATERIALS

'I will conduct research on physics- and data-driven computational methods for understanding the mechanics and physics of complex materials and structures – including metals, polymers, composites and architected metamaterials, as well as their manufacturing, such as thermomechanical processing and additive manufacturing. Contrary to the traditional approaches in materials by design – based on exhaustive simulations and experiments, computational design by data-driven and machine learning methods is the new frontier that offers quick identification and reduction of the design space, eventually leading to a faster turnaround of material production that meets the requirements. To this end, I will work towards the paradigm of the inverse design of materials where the challenge is to systematically and efficiently reverse engineer material designs and processing techniques to achieve tailored and/or extreme properties and functionalities.'

'The outcome of my research will contribute to a diverse suite of applications in materials. For example, my research on process design for sustainable production of metals will focus on improving the strength and durability of high-demand metals such as copper to mitigate the rapid depletion of natural ores, and pushing forward the viability of alternative metals such as magnesium for industrial and commercial products. My research on inverse-designed bio-mimetic metamaterials will focus on applications in personalised biomechanical implants – e.g. synthetic bone substitute that locally matches the properties of the natural bone for improving long-term compatibility and preventing bone atrophy. Other applications of my research include energy-absorbing composites, acoustic metamaterials, data-driven constitutive modelling and multiscale modelling of additive manufacturing processes.'

MATIN JAFARIAN
DATA-DRIVEN MODELLING AND CONTROL

'I will conduct research on the modelling, analysis, and control of complex biological networks with applications in both the engineering and health domains. My main research focus is modelling, analysis and the regulation of biological brain networks underlying human cognition, in particular memory, learning and decision-making. The importance of the mechanistic understanding of human cognition emerges from its central role in our health as well as being a main source of inspiration for addressing the need for active model learning and adaptive capabilities of future engineering systems.'

'The outcome of my research will contribute to novel medical and therapeutic methods in the area of human memory functioning as well as advanced solutions for future adaptive engineering systems. I will develop models using both knowledge-based and data-driven approaches, and utilise tools and techniques from dynamical systems and control theory, in particular nonlinear, discontinuous, hybrid and stochastic dynamical systems.'

'After capturing CO_2 from the air, I want to make fuel out of it, which can be used to run machinery in factories and to power cars and so on, as a renewable energy source'

USING SMART TECHNOLOGY TO MAKE FUEL OUT OF CO_2

Too much CO_2 in the air is currently causing a major problem: climate change. If it were up to Peyman Taheri, researcher at Materials Science and Engineering at TU Delft, we would be making smart use of surplus CO_2 by converting it into a new fuel. A fuel that could power factories and send cars hurtling down the motorway.

One of the main causes of climate change is the huge amount of CO_2 released into the air every day. It's emitted by cars, power stations and factories, for example. These large quantities are heating the earth up, melting (polar) ice and threatening to cause the sea level to rise at an alarming rate. This is a worrying development, according to TU Delft scientist Peyman Taheri.

He's therefore working with colleagues to find a solution. They want to capture CO_2 from the air, so it can no longer contribute to the climate change.

'After CO_2 has been captured,' Taheri adds, 'I want to make fuel out of it that can be used to run machinery in factories and to power cars and so on, as a renewable energy source'.

That's quite a turnaround. Instead of emissions that have highly detrimental consequences, this approach turns a problem into something that you can actually be used and has added value.

Getting everything out of materials

Taheri is still looking for a smart way to convert CO_2 effectively into a synthetic fuel. 'That's not so easy from a chemical point of view, because CO_2 consists of very strong bonds. So you need something that can break those bonds.'

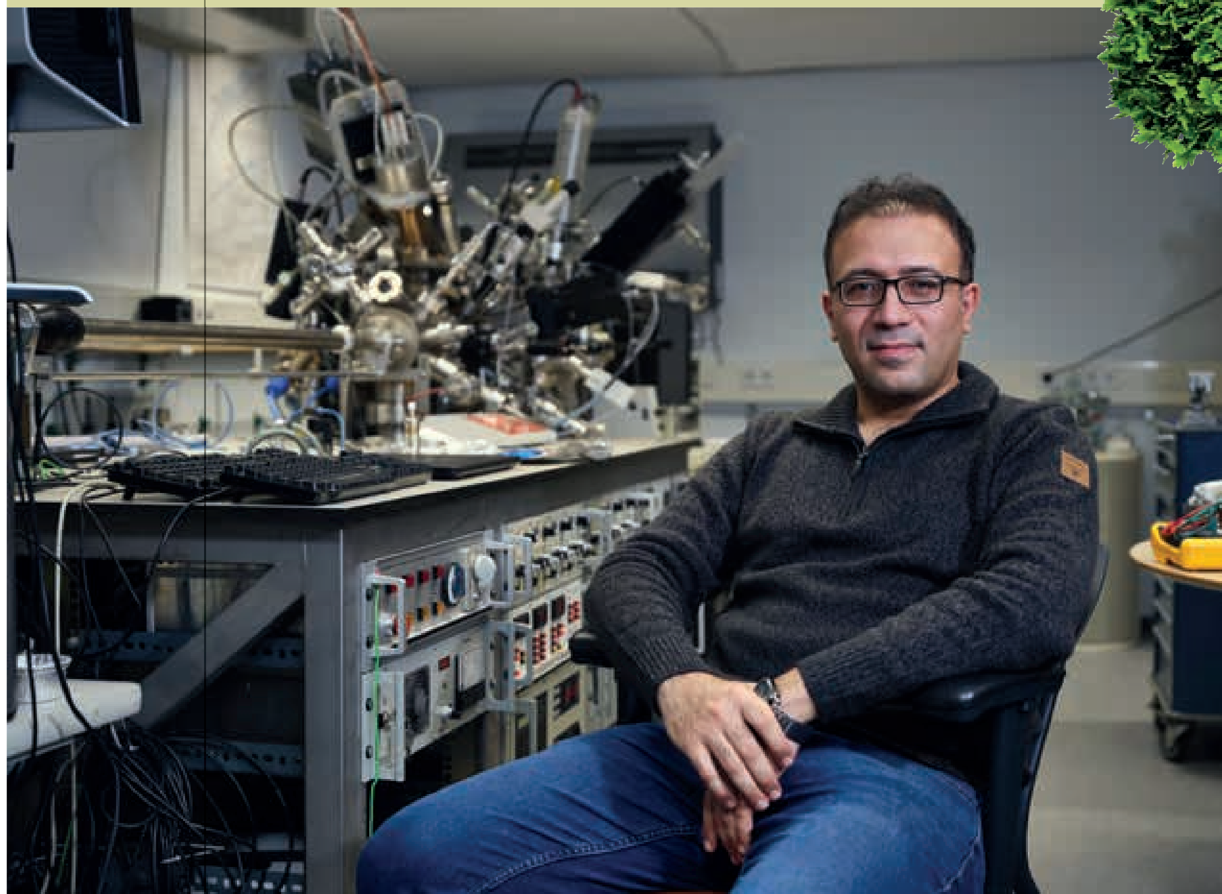
To do that, Taheri is working on so-called electrocatalyst materials converting CO_2 into synthetic fuels through electrochemical processes. This makes it possible to break the solid molecular compounds and make fuel out of them. 'We're manufacturing a new material for that purpose, which must have the right properties,' the scientist says. 'I do a lot of experiments. Sometimes I also test things that I don't quite understand yet. I always start by analyzing what the properties of materials are and whether they have the right composition to turn CO_2 into a fuel.'

Taheri studies different materials, including nanomaterials, metals and semiconductors. 'First I manufacture them, and then I examine their properties and tune them towards an efficient fuel production process. It's important to completely master the material properties. Only then you can really get the most out of this material.'

Valuable fuel

The end result should be the fuel, and if all goes well, soon you should be able to fill your car with it on the motorway. Imagine speeding down the highway on fuel that not only drives you forward but is also based on CO_2, which is causing so much inconvenience right now. It's not clear yet whether filling up your car will become much more expensive. 'That remains to be seen, but I think we can make this new fuel competitive,' the materials expert says. 'Making it available for exactly the same price won't be necessary in the near future, because this fuel does so much more as it also removes CO_2 from the air. That gives it added valuable.'
Taheri believes that in the near future CO_2 won't only serve as fuel for cars, but will also be captured right next to factories. 'Researchers are already working on devices that do this. It will then be possible to convert the captured CO_2 into energy, which will supply the plant with electricity. Scientists are already working on this.'
It's a tempting prospect that really motivates Taheri. 'Climate change concerns me, and I want to do something about it. I hope we'll find an increasing number of affordable, green solutions in the future. It would be great if we could eventually create a negative level of CO_2 in the air, so that more CO_2 is taken out of the air than is emitted into it. That will really help reduce levels. My research will hopefully contribute to that. I think it's my responsibility as an engineer and scientist not to stand on the sidelines, but to roll up my sleeves and use my energy and knowledge to solve the CO_2 problem.'

'I do a lot of experiments. Sometimes I also test things that I don't quite understand yet. I always start by analyzing what the properties of materials are and whether they have the right composition to turn CO_2 into a fuel.'



PEYMAN TAHERI
Assistant Professor at the department of Materials Science and Engineering

Filling the gap:

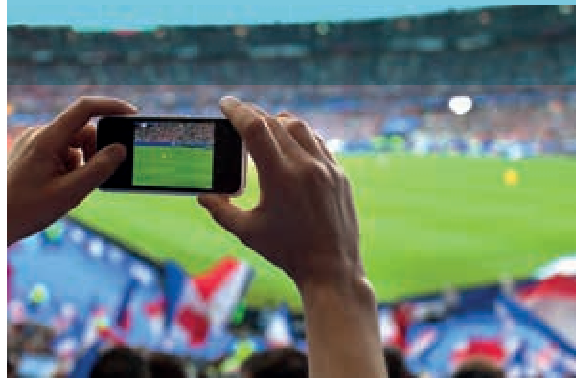
Terahertz waves for next generation sensing and communication

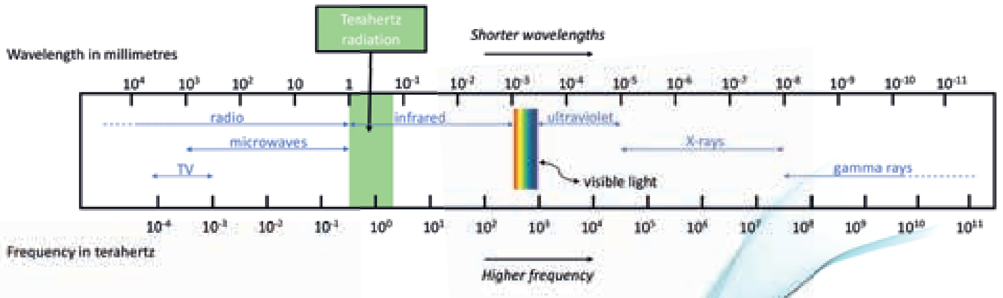
Developing technology for the terahertz region of the electromagnetic spectrum used to be a very expensive hobby, only pursued by space exploration scientists and the military. Maria Alonso-delPino uses advances in silicon chip technology to open up a whole universe of more worldly applications – enjoying the fundamental challenges that still need to be addressed.

In our daily lives, we are surrounded by technology utilizing microwaves and visible light. Think of Wi-Fi and and your microwave oven and, for visible light, your flat screen TV and cell phone camera. Falling right in between microwaves and visible light, the terahertz frequency band still faces many technological limitations that prevent its wide-spread application. Sources of this radiation are not powerful enough, detectors not sensitive enough and either of them not compact enough. 'It has led to what is called the terahertz technology gap,' says Maria Alonso-delPino. 'Over the last few years, however, cheap and mass producible silicon technology has opened up new applications for terahertz radiation; autonomous cars, medical imaging, ever faster wireless communications, anything that was not viable previously because of cost.'

As an assistant professor in the Terahertz Sensing group at the Department of Microelectronics, she uses her expertise in electromagnetics and system design to help fill this terahertz technology gap. 'I enjoy being involved in the very early stages of these breakthrough developments,' she says. 'I closely collaborate with researchers from the electronics group and other disciplines to build proof-of-concepts of solutions that can benefit society as a whole.'

> The much higher data transfer rates of beyond-5G technology will allow an entire soccer stadium to live-stream the match in Full HD.





TERAHERTZ RADIATION
One terahertz (1 THz) equals a thousand billion oscillations per second. Radiation in the terahertz region of the electromagnetic spectrum has frequencies of 0.3 to 20 terahertz.

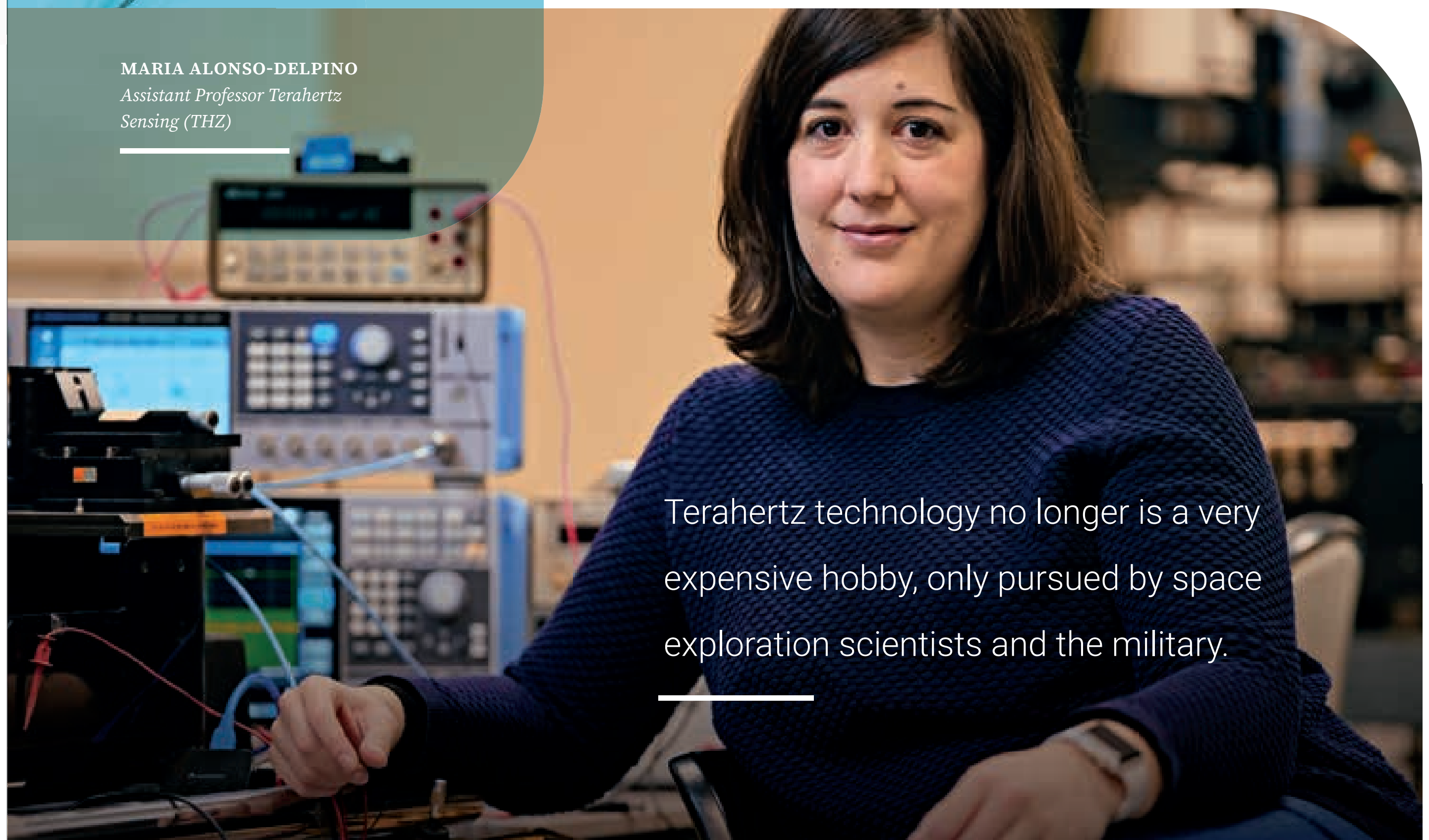
The common theme for all terahertz technology is that it has to have low-power consumption, low weight and be small.

Different applications, similar challenges
In her research, Maria Alonso-delPino focusses on the hardware side, designing high-frequency front-end radiating systems and how these are interfaced to the electronics that are further down the line. Many of the challenges she faced when designing state-of-the-art technology and instrumentation for space science at the NASA Jet Propulsion Laboratory still hold true. 'The common theme for all terahertz technology is that it has to have low-power consumption, low weight and be small,' she says. 'But now it also has to be low cost and preferably have new capabilities such as the ability to handle multiple frequencies and be able to steer the radiated beam. And, it should preferably consist of multiple pixels.'

Beyond-5G
One area where Maria Alonso-delPino is eager to apply her skills and let terahertz technology shine is wireless communication. Especially in crowded places – a soccer stadium or an open-air festival accommodating tens of thousands of people – the much-hyped 5G will never be able to provide most people with a good, or any signal. 'We want to solve this using what we call beyond-5G technology,' she says. 'In the Fly's Eye Project, we use much higher frequencies, allowing much higher data transfer rates as well as a substantial reduction in radiated power.' At just over half a meter in diameter, the Fly's Eye will hang in the middle of the stadium, covered in passport-photo-sized 'eyes', much like the compound eye of a fly. Each eye consists of a bunch of terahertz transmitters, receivers and a lens – their wide-angle beams overlapping to cover the entire stadium. 'I am building the antenna-systems for each of these little eyes,' Maria Alonso-delPino says. 'We also have to make it into an integrated and scalable system. Our goal, in a few years' time, is to demonstrate a proof-of-concept in the TU Delft Aula.'

Under your skin
Imaging is another application where terahertz radiation may be able to outshine, or at the least complement, existing technology. When it comes to imaging outside of the visible spectrum, we, as a society, are already quite familiar with the use of x-rays and infrared radiation. But x-rays are ionizing and therefore potentially harmful. And, compared to infrared imaging, terahertz radiation has the advantage that it can easily pass through certain materials, including clothes and even the first layers of the skin. This makes it very suitable for security applications and for certain medical diagnostics. 'Microwaves can pass through materials even more easily,' Maria Alonso-delPino says, 'but their much larger wavelength means that you lose out in resolution. Terahertz is the compromise between resolution and transparency.' Put simply, a doctor may not be able to properly identify a skin cancer with pixels the size of a Tic Tac. Within the TiCam project, Maria Alonso-delPino and colleagues would like to build a high-resolution camera at terahertz frequencies. One of the major challenges is for the camera to have a high-enough sensitivity to image just the radiation emitted by a person or an object – meaning that it doesn't require an external source for illumination. Maria Alonso-delPino: 'Initial steps at TU Delft resulted in a single pixel, created using standard silicon chip technology. Right now, we want to take the first images, using a mannequin. Our ultimate goal is for the camera to have a thousand pixels, allowing very fast thermal imaging through objects.'

A little wait
Once new technology has become a part of our daily lives, it is easy to forget that its development took some time. But digital cameras didn't arrive overnight, and it took twenty years to build a microwave oven that was affordable and that fit into a kitchen. The same holds true for terahertz technology. After proof-of-concept by Maria Alonso-delPino and her colleagues, industry needs to pick up on these ideas and develop them into fully fledged products. It is impossible to predict how long this will take. But when, at some future moment, you can live-stream Full-HD video from anywhere at anytime, you will know that the terahertz technology gap has been closed.



MARIA ALONSO-DELPINO
Assistant Professor Terahertz Sensing (THZ)

Terahertz technology no longer is a very expensive hobby, only pursued by space exploration scientists and the military.

HELP FROM ON HIGH TO SOLVE EARTHLY PROBLEMS

The ground beneath our feet is constantly moving and that can compromise the stability of buildings and infrastructure. Satellite data are helping Giorgia Giardina to chart the impact of subsurface activity on buildings in great detail so efficient measures to limit damage, cost and safety risks can be taken before it's too late.

> 'Based on a better understanding of what happens underground I try to determine the vulnerability of a building and the extent of any damage that may occur.'

Some parts of the Netherlands are sinking and none faster than the west and northeast of the country, where groundwater level decline and gas extraction are among the main culprits. And what happens below ground often affects what is happening on the surface, says assistant professor Geo-monitoring and Data Analytics Giorgia Giardina. 'Subsurface activity, such as ground subsidence, tunneling or earthquakes, poses a risk to surface buildings. Urban areas in particular can be badly affected, with buildings suffering severe subsidence and cracks. Without proper measures the damage to homes and other buildings will run into billions of euros in the years ahead. People's safety could also be compromised.'

GIORGIA GIARDINA
Assistant Professor Geo-monitoring and Data Analytics

'MY EUREKA MOMENT: WHEN I DISCOVERED THAT SATELLITE IMAGING COULD DETECT MOVEMENT IN BUILDINGS FROM A HEIGHT OF 600 KILOMETRES WITH UP TO THE MILLIMETRE ACCURACY.'

Below and above ground interaction

With a background in both environmental and civil engineering Giardina's area of expertise is where above and below surface activities meet. 'The interaction between what we can and cannot see has always interested me. Plus I'm from Italy, a country with a great many heritage buildings and a relatively high number of earthquakes. Based on a better understanding of what happens underground I try to determine the vulnerability of a building and the extent of any damage that may occur. For my Master's I worked on a risk evaluation of historical buildings in Italy. I then did my PhD in Delft, about the effects of the excavation work on the North South metro line in Amsterdam. I then went on to Cambridge to do a postdoc, and later started my own research group in Bath.

Help from on high

During her time at Bath Giardina spent much of her time working with space agency NASA. Her Eureka moment came when she was talking to one of the space scientists, Pietro Milillo. 'He told me that satellite imaging could detect movement in buildings from a height of 600 kilometres with up to the millimetre accuracy. That was a fascinating piece of knowledge and very valuable for the research I was doing. I had been using sensors to monitor individual buildings but now I could suddenly chart and study the movement of lots of buildings and infrastructure in a much larger area.'

Subsidence, maintenance and replacement

Last May Giardina decided to take up a post as assistant professor at TU Delft. 'During my time as a PhD in Delft I noticed how much knowledge is concentrated here from different disciplines such as Geo-Engineering, Remote Sensing and Data Science. I need all of these fields of expertise for my research. Apart from that, the Netherlands is an interesting place for study because it's facing so many challenges in terms of subsidence and maintenance of infrastructure and buildings. Many Dutch bridges are nearing the end of their life cycle and Groningen province is having to cope with a lot of damage to homes because of earthquakes. Our Dutch findings will help other countries with similar problems as well. Insights from the work on the North South metro line are now being used in the construction of the Crossrail project in London, for example.'

Damage assessment system

At TU Delft Giardina's job is to devise a method to assess the risks of subsurface activity. A damage assessment system, she calls it. 'It's a model which will enable us to estimate how a building will react to certain subsurface developments and where damage may occur. To do this we collect different types of data. Apart from the satellite data we need information about the behaviour of buildings and bridges. Concrete structures will react differently to subsidence than brick buildings. The stiffness of the material plays a role as well. We also need to know about the environment of the building, things like the surrounding infrastructure and the subsurface conditions. The tricky bit is to select the most relevant data and integrate it into the model efficiently. The use of satellite data for applications in civil engineering, for instance, is relatively new.'

Setting priorities

A good predictive model will help prioritise what needs to happen in terms of maintenance and replacement, Giardina says. 'Policy makers will have to decide which work should be done first. You can't do it all at once but if you know where the problems are most acute you'll know where to make a start. Timely interventions in the right spot will save a lot of time and money. The data will also help future building projects. If you know how buildings react to subsurface activity you can take precautionary measures in vulnerable areas, such as re-enforcing the soil or a building. Thanks to the satellite data you can also monitor movement during construction so measures can be taken in time.'

'I want to develop a damage assessment system, to help us estimate how a building will react to certain subsurface developments and where damage may occur.'

Prevent deaths and save heritage buildings

Giardina's work is not just about preventing damage and saving money. 'It is, of course, also very important in terms of human safety. A collapsing building can result in many casualties. If it does happen, for instance after an earthquake, you want to be able to bring people to safety as quickly as possible. The satellite images can visualise the damage and pinpoint the places for the emergency services to go, or to avoid as the case may be. Timely maintenance plays an important part where historical buildings are concerned. I'm from a country steeped in history and the Netherlands, too, is a treasure trove of historical buildings, just think of the canal houses. I live in one myself in Delft. For that to disappear doesn't bear thinking about.'

Is hydrogen-powered air travel the future?

Hydrogen is a sustainable alternative to kerosene-powered air travel because there are no CO_2 emissions. But hydrogen is also associated with challenges and risks, such as the danger of explosion. Ivan Langella aims to use mathematical models, high-fidelity computational simulations and experiments to develop a zero-emission hydrogen-powered engine that will enable aircraft to fly safely and efficiently.

IVAN LANGELLA
Assistant Professor Sustainable Aircraft Propulsion

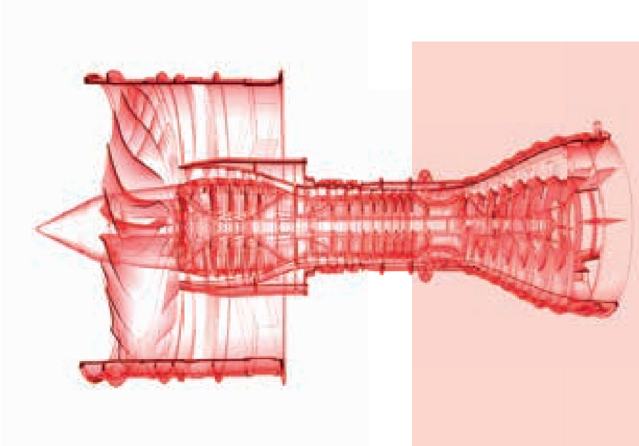
Although the coronavirus has currently left many aircraft grounded, aviation is developing at a rapid pace behind the scenes. Sustainability is one of the main reasons why this is happening. Currently, aviation accounts for some three percent of global CO_2 emissions, but with lack of alternative sources this figure could go up to a quarter of the global emissions in the next 3 decades. And this is without including dangerous emissions such as nitric oxides.

There is thus much scope for progress within the aviation industry when it comes to sustainability, says Ivan Langella, Assistant Professor in Sustainable Aircraft Propulsion. 'Existing kerosene-powered aircraft engines cause high levels of CO_2 emissions and pollution. If we want to combat further climate change, aviation will need to become much cleaner, especially if you take into account the ever-increasing number of flight movements. One of the solutions that could make a difference is the use of hydrogen. This is because hydrogen combustion does not release any carbon.'

Cleaner fuel, but there are risks

As an aerospace engineer specialised in fluid dynamics, Langella is playing an important role in the development of hydrogen engines for aircraft. 'Hydrogen-powered cars have appeared in the market, but there's not yet a hydrogen engine for aircraft that works effectively. Much more research is needed on what is feasible for aviation and how engines of this kind can be efficiently applied on aircraft, especially large ones. One of the key challenges is the instability of the flame at some engine conditions. This can lead to the flame propagating towards the tank, a phenomenon known as flame flashback, and consequently a significant risk of explosion. So, we need to improve the engines reliability.

> ***'We may see quite differently shaped airplanes in the sky in the future than we are used to.'***



'Designing the hydrogen engine as efficiently as possible in order to integrate it into an aircraft is another challenge.'

Despite the fact that a kilo of hydrogen is three times more energetic than a kilo of kerosene, hydrogen requires much larger tanks, even in liquid form. This means hydrogen-powered airplanes would be larger than kerosene-powered ones. The key will be to develop the hydrogen engine and storage tank without compromising on the weight and the aerodynamic efficiency of the aircraft, as this would mean more energy needed and thus more fuel consumption. This implies we may see quite differently shaped airplanes in the sky in the future than we are used to.

Complex processes within the gas turbine engine

A gas turbine engine is made up of several important components, explains Langella. 'We can broadly summarise these in a compressor that compresses and pre-heats the air from outside, the turbine that drives the compressor and the combustion chamber in which fuel and air are converted into energy. My research focuses primarily on the latter. I'm fascinated by how fluids interact and can be exploited to deliver energy. These processes are especially complex in aircraft combustion engines and involve a lot of physics and mathematics. But that's why I find it so interesting. I've been obsessed by aircraft from an early age. On a fairground roundabout, I used to love sitting in the aeroplane, a passion I have nurtured in the adult age by taking flight courses for small airplanes. I'm absolutely delighted that all of these aspects and interests come together as part of my job.'

Plenty of expertise and partners

Langella gained his Master's in Aerospace Engineering in Italy, where he was born. He then completed a PhD in Mechanical Engineering and held a post-doc fellowship in Cambridge. Next he was selected for the UK Excellence 100 scheme and worked as Lecturer in Thermofluids Science and Engineering at Loughborough University. He joined TU Delft as assistant professor last May. 'TU Delft is one of the world's leading universities in the field of aerospace engineering. There is a lot of knowledge here and the university offers extensive opportunities for experiments, simulations and data processing using powerful computers and top laboratories. The Netherlands is also at the forefront in the development of hydrogen technology. Not only industry, but also the government is investing heavily in clean-energy research. I'm able to do a lot of work with aircraft manufacturer Airbus and KLM here, whose long term priorities are still oriented for zero-emission flights despite the current suffering due to the coronavirus.'

Perfect power and emission balance

With his research group in Delft, Langella is working on the development of a hydrogen engine in various ways. 'One thing we're investigating is how to stabilise the flame in the combustion chamber. The combustion of hydrogen generates mainly water vapour but also nitrogen oxides (NOx). You need to minimise these emissions as far as possible, because NOx are damaging in high concentrations. A relatively new technology – known as lean-burn technology – can allow this but often results in an unstable flame as well. That's why we're aiming to strike the right balance. I'm working on mathematical models and very powerful numerical computations in order to investigate the behaviour in the engine. Based on that, we can make assumptions and predictions that we then test in experiments with a prototype. If an assumption proves correct, we scale up the experiment. We'll continue like this until we have a stable and nearly 100% clean flame. It's very much a step-by-step process.'

'I'm working on mathematical models and very powerful numerical computations in order to investigate the behaviour in the engine'

Impact on the environment, society and knowledge

Langella is enthusiastic about the idea that his research is contributing to the development of cleaner technology. 'It does not only matter for the environment, but also for society as a whole. The quality of air and nature is very much associated with the quality of human life. That means the research has an important social value. Another interesting factor is that this technology also has the potential for use in power plants, addressing the world's increasing energy demand in a sustainable and clean way.

The physical aspects underlying the technology are similar, although application in aircraft engines is slightly more complicated – as you cannot increase weight in aircraft as easily as you can in power plants. Thanks to strong investments in hydrogen research, the Netherlands and Delft University of Technology are positioning themselves a step ahead to affirm their role of global leaders in both hydrogen technology and clean aviation'

Several types of hydrogen engines

What the hydrogen engine aircraft will ultimately look like is still difficult to say, according to Langella. 'Several solutions are possible. We're certainly not the only researchers working on this. And in Delft we're also focusing on various subjects, including an engine that runs on a mixture of hydrogen and kerosene. Obviously, it's not completely emission-free, but will still contribute to reducing an aircraft's carbon footprint. That would be a great step forward in itself. An airplane mounting a hybrid engine could also be developed more quickly, potentially within five to ten years. Using an engine that runs completely on hydrogen calls for major adaptations. Aircraft will need to be equipped with different fuel tanks and engines, and fuel transport will have to be arranged differently at airfields.'

Higher price, but environment takes precedence

Another important area of focus is the way in which hydrogen is produced, concludes Langella. 'One method for producing hydrogen is from water via electrolysis. But that process itself also requires energy. If you use fossil sources for that, you're still not really flying sustainably. Designing the hydrogen engine as efficiently as possible in order to integrate it into an aircraft is another challenge. It's highly likely that hydrogen will prove to be a slightly more expensive fuel than kerosene, at least initially. But, in view of the advantages it delivers for people and the environment, that's something we'll just have to accept.'

FUTURE RESEARCH

The spotlight in this Fundament magazine is on 15 researchers who have been working on their research at TU Delft for some time. But positions are still being filled and so new researchers are starting each month. Who are our newest talents and what will they be focussing on?

HANIEH BAZYAR
MULTIPHASE FLOW FOR LOW-CARBON SYSTEMS

'I will conduct research on the development of the next generation "bio-based" membranes. Petroleum-based nonbiodegradable polymers account for 95% of the total materials used for membrane fabrication. Considering the increasingly severe energy crisis and environmental pollution problems, improving the sustainability and promoting the green transformation of the membrane technology is imperative. Apart from membrane technology, I will also focus on investigating the other potential application fields of bio-based polymers such as biomedical (e.g. drug delivery) and sensing applications. This further requires development of bio-based stimuli-responsive materials.

The outcome of my research will contribute to the development of a sustainable cycle in which bio-based polymeric materials, derived from waste (e.g. wastewater or organic waste), can be used in separation applications such as wastewater treatment. This approach can also contribute in developing carbon-neutral processes in various fields such as energy, environmental and resource management.'

LAURA MARCHAL CRESPO
HUMAN-ROBOT INTERACTION

'I will conduct research on the general areas of human-machine interfaces and biological learning and in particular the use of robotic devices and virtual reality (VR) for the diagnosis, treatment and rehabilitation of neurological patients. My research interests are at the intersection of engineering and neuroscience, and I investigate neurological phenomena using cross-disciplinary approaches from both domains. A major goal of my research is to gain a better understanding of the underlying mechanisms associated with the acquisition of novel motor skills to develop innovative technology to improve neurorehabilitation.'

'The outcome of my research will enhance the recovery of brain-injured patients. I aim to transform robotics and VR into effective and standardised tools in healthcare that can be found ubiquitously and used effectively with minimum training and to maximum effect. I will develop cutting-edge technology – e.g., immersive VR, robotic devices and controllers, and hybrid AI – to record, analyse, adapt and respond to users' motor, sensory and cognitive needs to maximise learning.'

DOMINIC VON TERZI
FLUID DYNAMICS FOR TRANSITION TO LOW CARBON ENERGY SYSTEMS

'I will conduct research on wind turbines and related flow physics.'

'The outcome of my research will contribute to the transition to clean energy for a carbon-neutral world.'

SIJUN DU
AUTONOMOUS SENSOR SYSTEMS

'I will conduct research on energy harvesting. The advances of electronic engineering has made our lives easier and our work more efficient in the past decades. However, batteries are holding up tech breakthroughs while battery technologies does not catch up with electronic advancements. A good example is that our cellphones are getting smarter while having shorter battery lives. To address this issue, harvesting energy from environments becomes a promising solution by harvesting ambient renewable energy, such as sunlight, heat, kinetic vibrations, electromagnetic waves and bio wastes, and converting it to electricity. In my research, I aim to explore novel energy harvesting techniques and power management systems to power electronics continuously and ubiquitously.'

'The outcome of my research will contribute to making electronic systems fully autonomous and self-sustained. With energy harvesting, patients don't have to take surgeries for replacing batteries in biomedical implants; wireless sensors can operate continuously and independently; we don't have to charge our smartphones or smart bands every a few days and smart cities can be truly smart without periodically charging or replacing batteries in millions of devices.'

DIMITRIS BOSKOS
DATA-DRIVEN MODELLING AND CONTROL

'I will conduct research on robust uncertainty quantification and its applications to data-driven control. My motivation comes from problems that entail dynamic random elements about which the designer seeks to make inferences using a limited amount of data, which is typically gathered online and may only reveal partial-state information of the process. I am therefore interested in leveraging results from state estimation and uncertainty quantification to fuse information from both the data and the system dynamics and obtain reliable uncertainty descriptions for decisions and control.'

'The outcome of my research will contribute to the development of methods and algorithms that account for environmental and model uncertainty, computational tractability, and system constraints, and will find applications in domains such as robotics, energy and transportation. To this end, I aim to integrate tools from filtering, adaptive control, nonparametric statistics and robust optimisation.'

BARIS CAGLAR
SUSTAINABLE DESIGN AND MANUFACTURING OF MATERIALS

'I will conduct research on fundamental problems associated with manufacturing of thermoplastic composites, through novel experimental and numerical techniques.

'The outcome of my research will contribute to the development of efficient processes for next generation smart-composites with reduced CO_2 footprint and improved circularity.'

ANDRES HUNT
ADVANCED MATERIALS FOR EXTREME CONDITIONS

'I will conduct my research on the embedding of sensing and actuation into mechanical metamaterials. My research will focus on using electronic and ionic smart material transducers, and novel designs of conventional transducers. Metamaterials are materials that exhibit exotic properties uncommon in nature, and smart material transducers are material level sensors and actuators, such as piezo electrics. By making the mechanical metamaterials active, we will be able to create materials that exhibit tailored mechanical properties and allow ubiquitous sensing and control over the entire material volumes or surfaces.'

'The outcome of my research will contribute to innovating human-machine interactions with increasingly interaction-capable materials for sensing and reacting to touch, and to high-tech engineering with highly controllable materials for actuation, suppressing vibrations and correcting deformations.'

Airplanes cross borders

So do their environmental effects

When it comes to the health effects of aviation, reducing total fuel burn may not necessarily be the optimal strategy. And, perhaps even more surprisingly, your flight from Amsterdam to Rome contributes to premature deaths in Asia. Irene Dedoussi models the global human health impact of air pollution from aviation emissions, helping both airplane designers and policy makers in weighing the various mitigation strategies to make aviation sustainable.

At university, the elegance of fluid mechanics prompted Irene Dedoussi to major in aeronautics rather than civil engineering. Then came an internship on aircraft noise at the German Aerospace Centre, where she expected to be looking into engine acoustics. 'But during landing, it is the landing gear that creates the most noise,' she says. 'I found that strange and interesting. It made me curious about the other environmental aspects of aviation and how best to address these.' Now, as a tenure track assistant professor, she is establishing her own group on emissions and air quality within the Aircraft Noise and Climate Effects section. 'TU Delft is the ideal location for me to do this research as it is one of the few universities in the world that looks into all the environmental aspects of aviation,' she says. 'To achieve sustainability, we can't look at noise, air pollution or climate effects in isolation. There are real trade-offs between these environmental effects.'

From fuel-burn to health effects – anything but straightforward

Burning airplane fuel doesn't only create CO_2 – a major contributor to global warming – but, among others, also nitrogen oxides (NOx). By chemically interacting with the atmosphere, these nitrogen oxides lead to the creation of fine particulate matter and ozone. Both of these are harmful to human health, for example causing respiratory diseases, ultimately leading to premature deaths. 'There isn't a one-to-one relationship between fuel burn and health effects,' Dedoussi says. 'For one, increasing the airspeed and burning fuel twice as fast may more than double the amount of nitrogen oxides released.' The chemical reactions within the atmosphere are also non-linear. They depend on the chemical composition of the atmosphere which is influenced by emissions from other sectors, such as heavy industry and road transport. And there is a complicated relationship between air pollution and its health effects. Doubling or halving emissions does not mean that the health effects are doubled or halved. 'All of these relationships need to be carefully modelled,' Dedoussi adds, 'and they come with a lot of uncertainties that have to be addressed.'

'To achieve sustainability, we can't look at noise, air pollution or climate effects in isolation.'

Local emissions, global implications

By its nature, aviation is a sector that is international. Therefore, global simulations are needed to assess the health impact of cruise level emissions. In her simulations, Dedoussi takes into account all the effects mentioned above as well as (global) atmospheric circulations patterns. It has resulted in insights that are sometimes quite surprising. 'The health impact of nitrogen oxides depends on where they are released into the atmosphere,' Dedoussi says. 'Airplanes are optimised for flying fast and at high altitude largely because of economic reasons. This would, perhaps, be different if the environmental costs are fully taken into account.' Burning a ton of fuel over Europe has over fifty percent higher global health impact compared to burning the same amount of fuel over North America or Asia. 'From a global perspective, caring about all people equally, we should first address aviation over Europe,' Dedoussi says. 'But because of the circulation patterns in earth's atmosphere, you will see most health improvements in Asia. If you want to fix air pollution in Europe, you have to also look at aviation outside of Europe.'

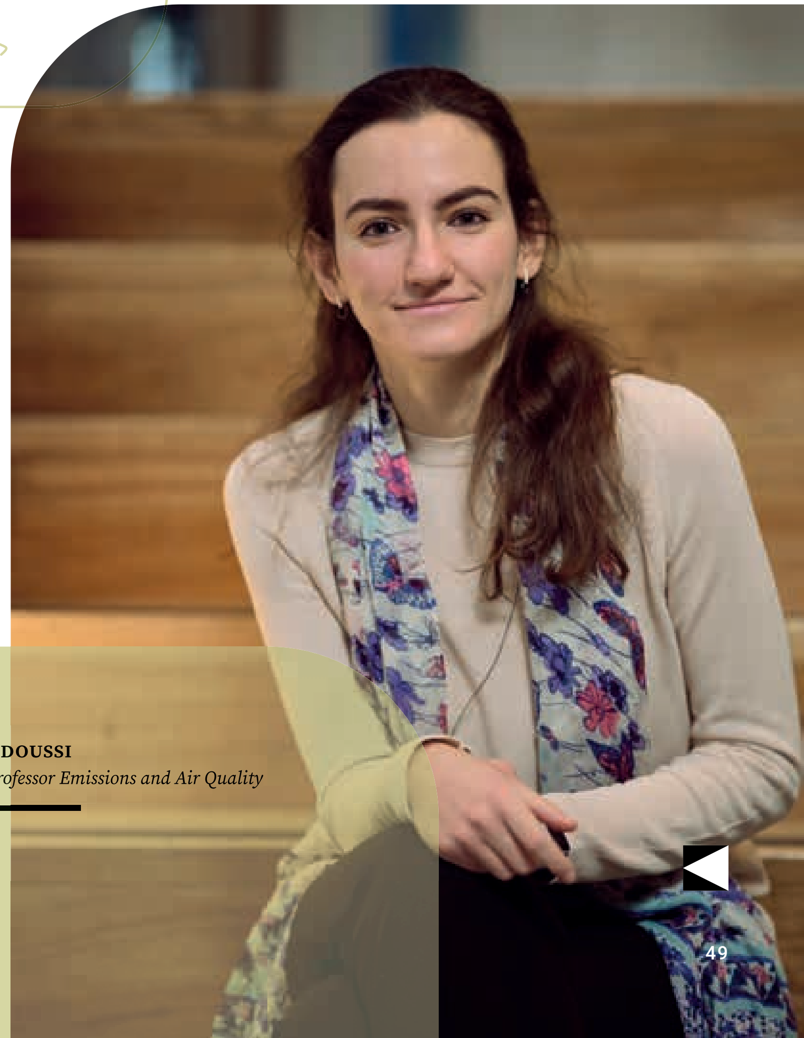
Healthy policymaking

Before joining TU Delft, Dedoussi obtained her PhD on the atmospheric impacts of ground-level and high-altitude combustion emissions at the Massachusetts Institute of Technology. That was when she also became interested in the overlap with policy. 'I quickly learned that policymakers have a hard enough job to do as is', she says. 'They really shouldn't also have to worry about the atmospheric non-linearities, about the details in the underlying physics. We, as scientists, have to give them the tools that help them in practice. It can't be an algorithm that takes weeks to run on a supercomputer. It has to be as simple as an excel spreadsheet.' Dedoussi and her colleagues do try to speed up their current simulations, but what is unique about their approach is that they design their experiments to look at how perturbations in the emissions affect global health. Then, it is easy to scale the health effects based on how much each policy or technology – a different engine, a flying-V design – perturbs the emissions. 'It would probably be naïve to think that the health impact of flying will be completely taken into account in airplane design and the price of tickets,' Dedoussi says. 'But at least now they could play a role in the cost-benefit analyses.' For her research into combustion emissions, she was recently recognised as a Forbes 30 under 30 in Europe's Science and Healthcare category.

'We, as scientists, have to give policymakers the tools that help them in practice.

A look into the future

When moving to the Netherlands, Dedoussi quickly became involved in the somewhat- uniquely Dutch discussions on the deposition of nitrogen, even providing expert advice to a national advisory committee. 'This is currently not being fully assessed for aviation,' she says. 'Especially the contribution of high-altitude emissions, if any, is completely unknown.' She is also acutely aware that the health and nitrogen deposition effects of aviation may change over time. That is why she recently applied for, and received, a VENI grant. 'In the future, we may have higher global average temperatures,' she says. 'Or the ammonia content of the atmosphere may change, which influences how nitrogen oxides react to form fine particulate matter. I want to model these sensitivities so that they can play a role in current technology and policy decision-making.' In that respect, COVID-19 travel restrictions and lockdowns have provided a unique opportunity. 'The data being gathered right now will be very valuable in understanding how our atmosphere responds to emissions, and how aviation contributes to the atmospheric composition,' she says. 'But other sectors, such as road transportation, have also been greatly affected. Again, we have to take the complete picture into account.'



IRENE DEDOUSSI
Assistant Professor Emissions and Air Quality

Good vibrations?

Not for bridges

Due to poor monitoring, many structures are not maintained properly or on time. This results in safety risks and high costs for overdue maintenance. Researcher Alice Cicirello is working on better design and monitoring tools to ensure the secure construction of structures to extend their service life.

ALICE CICIRELLO
Associate Professor in Dynamics and Monitoring of Engineering Structures and Head of the Mechanics and Physics of Structures section

Premature failures of bridges, pipelines, offshore wind turbines or offshore support structures in operation can have severe consequences, such as loss of lives and unforeseen disrupting downtimes which can have safety and economic repercussions. In August 2018 Italy was shaken by the sudden collapse of the Morandi Bridge in Genova. 43 people lost their lives in what was later found to be an avoidable disaster caused by years of deferred maintenance. 'This tragedy shows the importance of constant monitoring of structures such as bridges,' associate professor and head of the Mechanics and Physics of Structure section Alice Cicirello says. 'Proper monitoring will reveal the condition of the bridge so any potential risks or damage can be tackled in time.'

In the Netherlands too bridge maintenance has been found lacking. Recent research showed that the Merwedebrug, closed to traffic in 2016, is on the point of collapsing. In 2018 the Dutch government spent around €400m on the deferred maintenance of bridges.

Failing monitoring systems

Monitoring of engineering structures is carried out by means of sensors which collect data which in turn are used to learn about the condition of the structure,' Cicirello says. 'The problem is that these sensors are often in the wrong place, or faulty because of age or damage. That means the data they provide may be incomplete or incorrect. This might cause missed detections of unsafe structural conditions. Moreover, a faulty monitoring system can undermine the reasons for implementing monitoring technologies in the first place. For instance, if a structural problem is wrongly detected with a faulty sensor, the monitoring system will give a false alarm. This would effectively lead to an unnecessary close down of a healthy bridge causing huge detours for traffic. What I want to achieve with my research are better monitoring strategies and design tools which will improve structural performance and longevity. That is a major goal, considering the enormous maintenance and

‘What I want to achieve with my research are better monitoring strategies and design tools which will improve the performance and longevity of structures and infrastructures for transportation, supply of energy and communication which are of critical importance for our society.’

replacement challenge the Netherlands is facing. Many bridges in this country are nearing the end of their life cycle.’

Vibrations and other wobbles

Before Cicirello came to Delft in January 2020 she earned a bachelor’s and a master’s degree in Civil Engineering in Italy and a PhD in Mechanical Engineering at the University of Cambridge. She also worked in industry and lectured at the University of Oxford. Cicirello’s research is centred around vibration. ‘Everything around us vibrates. Vibration enables us to hear sound and communicate with each other. But vibration is also a cause of structural defects or noise disturbances, not just in bridges but in cars, wind turbines, drilling tools and all sorts of other engineering devices and objects. So in order to make the engineering structures last longer you have to understand their vibration. The problem is that the dynamic response of a large scale engineering structure made of many components can be very difficult to predict. ‘There will always be a number of uncertainties that influence their behaviour and lifespan. For bridges, these include weather conditions, such as wind speed and temperature, and the impact of traffic.’

Uncertainties

For Cicirello such uncertainties represent not an obstacle but a challenge. ‘In science as in life, we have to face the fact that there are many things that we do not know precisely, and other things that are subject to an inherent variability. Nonetheless we have to make decisions under these uncertainties. The question is not so much how we can control these uncertainties but how we handle them. One of the ways to tackle them is for example to minimise their effect. Robust design can make structures as resilient as possible against the effects of wind speed or heavy traffic which are not fully known at the design stage. A good monitoring strategy will then help to accumulate life cycle data about unforeseen events and external factors so action can be taken.’

‘I look at physics, build mathematical models, experiments, quantify uncertainties and use machine learning techniques. Such an integrated approach is important because it gives me a comprehensive picture of the behaviour of the whole of the structure.’

Integrated research approach

In 2017 Cicirello set up the Dynamics, Vibration and Uncertainty Research Group at Oxford and started a laboratory to look simultaneously at these various aspects from different angles. She brought this expertise to Delft, where she is setting up the Monitoring, Vibration and Uncertainty Lab. ‘We look at physics, build mathematical models, experiments, quantify uncertainties and use machine learning techniques. An integrated approach is important because it gives us a comprehensive picture of the behaviour of the whole of the structure. Without experimenting, for instance, you won’t know if the assumptions in the model are correct. And we need monitoring and machine learning to collect and process data that will help us learn the behaviour of the structures during operating conditions,’ Cicirello says.

A digital copy of reality

An integrated approach, Cicirello explains, will help engineering structures last longer. ‘It starts with the collection of information about the structure, its shape, material and environment. Based on this information, a representative computer model of a structure is build. This acts as a virtual replica of the structure, the so-called digital twin, which enable us to explore the performance of the structure before it is built and also during its life cycle. For example, a digital twin of a bridge can be developed. We can then take into account for uncertain elements, such as strong winds or heavy traffic. That will flag up the critical and vulnerable spots in the bridge. This not only helps promote robust design but also determines where the monitoring sensors should be placed. Once the bridge is in use you can use the data provided by the sensors to update the digital twin, enabling ever more accurate life cycle predictions.’

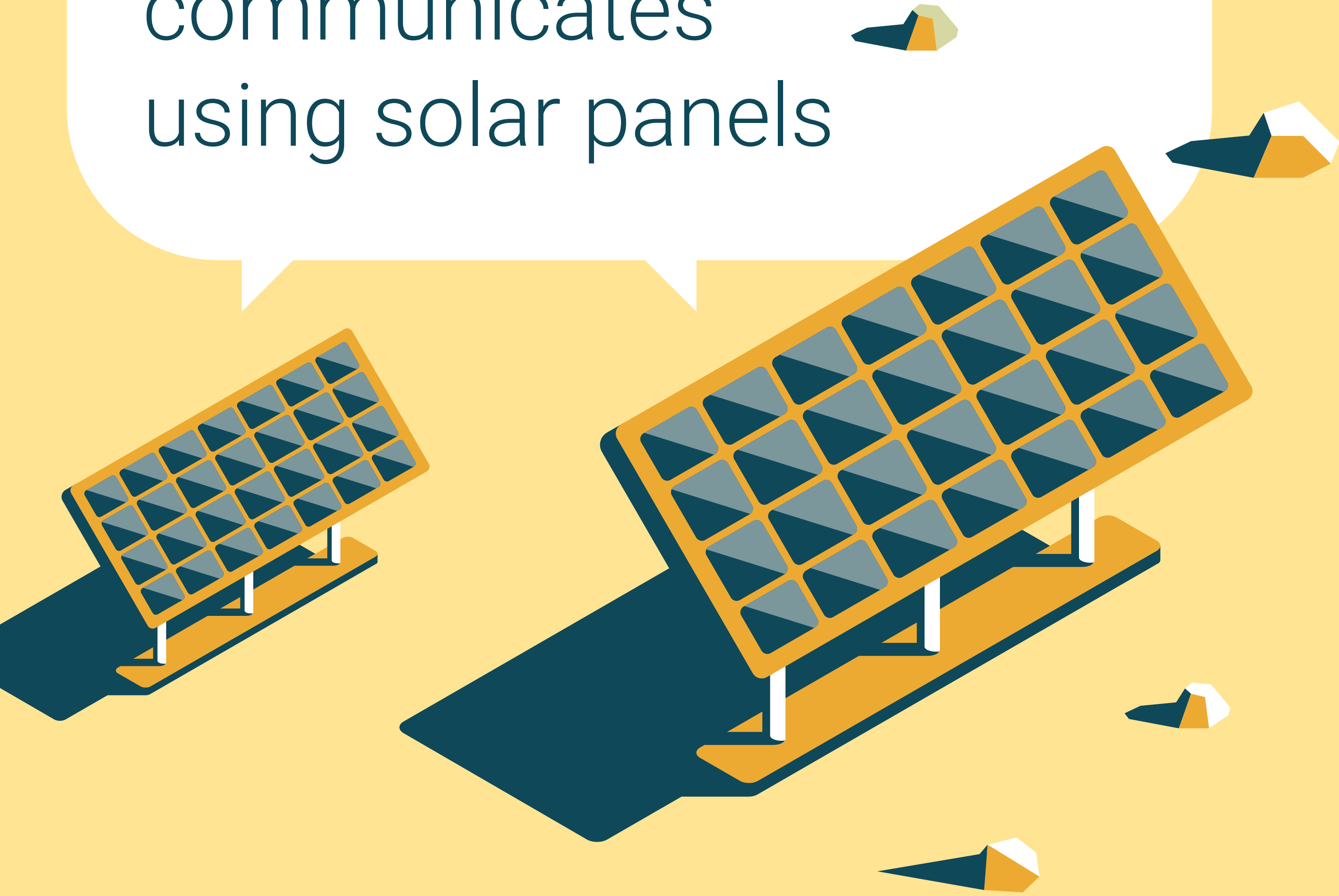
Advantages

Robust design and better bridge monitoring come with a number of advantages, Cicirello says. ‘The main thing of course is to keep people safe. We have only to think of the lives lost in the Morandi Bridge collapse. A better understanding of the vulnerable spots also ensures that maintenance is carried out at an early stage and in the right places. It is also money saved as preventive maintenance is much cheaper than deferred maintenance. The digital twin approach also extends the life cycle of the structure which saves on materials and energy and so benefits the environment. Better monitoring also prevents avoidable delays caused by false alarms.’

Partners

For her research Cicirello has partnered up with a number of parties in the field, such as the ministry of water management and infrastructure Rijkswaterstaat. ‘Rijkswaterstaat is responsible for the monitoring and management of many critical structures in the Netherlands. Together we look at how their current monitoring system can be improved. Where are the best spots to put the sensors, how do we prevent the failure of the monitoring system and how do we determine when maintenance and repair work should be carried out? We hope that within five to ten years we will have a number of effective tools in place to make effective monitoring happen in practice.’

City of the future communicates using solar panels



If it is up to Patrizio Manganiello, the city of the future will not only run on solar energy, but we will also use the solar infrastructure for lightning-fast communication. Buildings will autonomously regulate how power is distributed between them and self-driving cars will use light signals to coordinate their driving manoeuvres. The new field of research called Photovoltatronics is bringing this future closer.

Electrical engineer Patrizio Manganiello was sitting in a lecture in Italy at the start of this millennium when he was suddenly hit by the undeniable reality of the disturbing headlines. During a course on renewable energy sources, his professor showed the students two graphs; one displayed the trend in global energy consumption, steeply rising like the flank of a mountain, while the other showed a red line, zigzagging but clearly going up. This was the surface temperature on earth. 'The professor factually described the correlation between the two graphs, explaining why it is so important for us to find alternative ways to produce energy,' says Manganiello. It was this eye-opener that drove him to devote his time to the search for smart alternatives for sustainable energy production.

Nearly twenty years later, Manganiello is now plunging into the new research field of Photovoltatronics, where solar cells and electronics merge. In a nutshell, he wants to design solar cells that not only convert light into energy but are also able to send and receive information. This would not only concern information about the operation of the network of solar cells, but also other types of information, such as an impending disaster. Manganiello sees his work as a necessary search for a sustainable but above all fascinating future, a future in which solar panels exchange information to optimise their operation and self-driving cars use solar cells to communicate information about routes and traffic safety. 'Almost anything you can imagine is possible.'

Senses and communication

Manganiello compares the current solar infrastructure with a creature that cannot see or feel. It is his ambition to provide solar cells and modules (groups of electrically connected solar cells) with these senses and enable them to communicate with each other and with the world. The crux of the technology involves deploying the existing infrastructure of a solar cell not only to convert light (photons) into charged particles (electrons), but also to provide them with sensors that can extract information from the light waves and enable them to broadcast their own light messages using LEDs or other light sources.

Photovoltatronics – a brand new field of research at the Electrical Sustainable Energy department – focuses on the biggest obstacles to integrating energy production and information exchange. What possible uses are there for materials that can both absorb and emit light, so that they combine the two functions? How can you integrate LEDs and sensors in solar panels, for example? 'In the Photovoltatronics research group we see a future based on solar energy,' says Manganiello. 'We want to get as much as

'In time, all the buildings in a city will be able communicate with each other and warn each other in the event of a fire, storm or flood, for example.'

possible out of these solar modules both in terms of energy and information exchange, which will be particularly important for ensuring a sustainable energy supply in our cities.'

Front of clouds

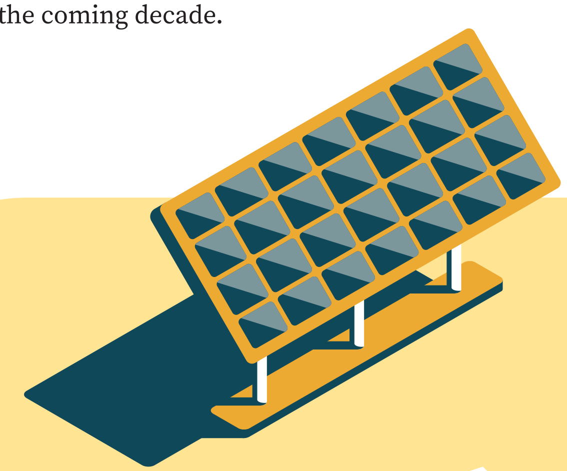
Conducting measurements and passing on this information can primarily increase the efficiency of solar panels. For example, a solar panel that is equipped to measure light intensity and temperature distribution can also detect a passing front of clouds. The panel can then switch from series to parallel, so that the reduction in power of the solar cells in the shade does not hinder the energy production of those still in sunlight. When the sensors register that the front of clouds is moving away, the panel can send a signal to a central switching point: 'I am about to peak; prepare the energy network.' This will prevent network overloading and instability.

But Manganiello also has plenty of ideas for more creative applications for integrating energy generation and information transfer, in particular as part of the increasingly wide-scale integration of solar cells in urban environments in the coming years, where solar cells could be built into windows and walls, but also indoors to capture and reuse energy from artificial light. For example, a desktop covered with solar cells could convert the light produced by a desk lamp into energy to wirelessly charge a phone.

The electrical engineer holds his outstretched hands in front of his chest to illustrate two buildings opposite each other in his vision of the city of the future. If their walls can not only generate energy, but also exchange information through multifunctional solar panels, the buildings will be able to communicate with each other. For example, one building could report that too many washing machines are being used in it and that it requires extra power from its neighbour. Or they could share an internet connection using light signals. This could be of real benefit with the increasing scarcity of radio waves used for Wi-Fi. In time, all the buildings in a city will be able communicate with each other and warn each other in the event of a fire, storm or flood, for example. 'LED lights in an office building could send a signal to a sensor on your phone warning you to leave the building,' says Manganiello.

Self-driving cars

Manganiello explains that he has thousands of ideas for experiments to bring these futuristic scenarios closer. 'Unfortunately, at any given moment we can only work on a tiny percentage of these, which is what I find most frustrating about my work.' He estimates that it will take about 10 to 15 years before new buildings will be able to communicate with each other through solar cells built in to their walls, however the first applications should start to appear in the coming decade.



> Patrizio wants to design solar cells that not only convert light into energy but are also able to send and receive information.

PATRIZIO MANGANIELLO
Assistant Professor of Photovoltatronics

Manganiello is impatient to get moving. 'Energy is playing an increasingly important role in our lives. Our biggest fear today is that our battery will run out,' he says. The graphs that made such an impression on him as a student twenty years ago have shot up even further. 'I want to believe that we can solve this, but when I see how societies, governments and the industry are responding to these issues, I sometimes lose heart.' He sighs deeply when asked to provide an example of such a response. 'The main problem is the resounding lack of a response, and the low priority given to sustainability.'

Despite the severity of the problem, optimism and fascination still prevail in the interview with Manganiello. He concludes by sharing his favourite scenario for a sustainable future that the Photovoltatronics group hopes to achieve.

He describes two cars, covered with solar cells which provide a large part of their energy. A deer suddenly jumps out in front of the foremost car. Even before it has applied the brakes, its rear lights rapidly transmit a signal to the solar cells on the vehicle behind: 'Warning, I'm about to brake!' At the same time, the urban traffic control centre sends signals via street lamps to solar cells on the roofs of passing cars to control traffic and prevent congestion and air pollution hotspots.

'I think this is the best example, because safety is the main bottleneck in the development of self-driving cars, while this technology can make life easier and more sustainable. I think the Photovoltatronics research group can provide an important boost to the development of self-driving cars, and it is a privilege to be able to contribute to this.'

NATURE INSPIRES NEW MATERIALS

'Creating new materials by learning from nature. That's what Mohammad J. Mirzaali is working on. He looks specifically at hard and soft transitions, which connect a hard bone to a piece of soft tissue in our bodies, for example.'

> ***If someone has bone cancer and the surgeon removes a piece of bone, he or she replaces it with an implant. But that's not as easy as it sounds. It has to be attached to a bone, which is hard, and to tissue, which is very soft. These kinds of transitions are difficult for materials to handle, because they have to be firm, but at the same time they must not damage the soft tissue.***

'We're looking for ways to make materials that work well in these kinds of transition zones,' says researcher Mohammad J. Mirzaali from TU Delft's 3mE Faculty. So you can make a better implant, for example. But it can also be used in aircraft construction. An example familiar to us all shows just how important these kinds of hard and soft connections are. 'The plug of your phone charger has a hard part that you insert into the phone, but also a cable, which is softer. The transition from the hard plug to the cable breaks with most people. That shows how difficult it is to design this well. Because obviously you don't want a charging cable that keeps breaking.'

Nature as inspiration
How do you make such a material? Mirzaali gets his inspiration from nature. 'I let it inspire me. Nature has wonderful, ingenious solutions for all kinds of problems. When Leonardo Da Vinci wanted to build a flying machine, he also looked at birds and flies. I use a similar approach. I look for examples from nature that can inspire me.'

He finds them in our bodies, for example. 'I examine the mechanism behind the transition from bone to tissue in our bodies and I try to imitate that,' Mirzaali says. He then looks at the stiffness, which is much higher in the bone than in the soft part. 'There is a very small transition. What we see when we look inside with special microscopes is so complicated. I want to understand exactly what's at play in this transition and how it works. There's definitely a hierarchy of different particles involved. If I can learn to understand how that works, then I can recreate it.'

That's why the scientist investigates tiny particles. 'I really look at the forces and the structures at the cellular level. By the way, it would be a problem to create this on an industrial scale, because we can't make everything as small as nature does.'

Forces at the nano-scale

For his research, Mirzaali collaborates with many colleagues from other backgrounds. For example, he uses insights from scientists who examine the tiniest components of our world, at the nano-scale. 'This is what's referred to as the microfabrication of small particles. Using artificial intelligence, we're trying to find out how certain transitions from hard to soft have been designed by nature, why they work and what different types there are. These kinds of collaborations always yield new insights. For example, that the interrelationships of the particles play an important role, that some designs cause certain cells to grow much faster and how individual cells affect the formation of a material. By looking at which forces are at play on the nanoscale, we can make better models for developing new materials.'

> ***'If we succeed in creating a new material, many people will benefit from it. It can still be used for many different medical applications, because we have many of these kinds of transitions in our bodies. Think of people with osteoarthritis. They have problems with their bones and tissue. It's estimated that around 30 to 50 per cent of people over 60 suffer from it.'***

Nature has wonderful, ingenious solutions for all kinds of problems. When Leonardo Da Vinci wanted to build a flying machine, he also looked at birds and flies. I use a similar approach. I look for examples from nature that can inspire me.'

MOHAMMAD J. MIRZAALI
Assistant Professor Biomimetics, Biomaterials & Bioengineering

What really appeals to Mirzaali is that his research is contributing to society. 'If we succeed in creating a new material, many people will benefit from it. It can be used for many different medical applications, because we have many of these kinds of transitions in our bodies. Think of people with osteoarthritis. They have problems with their bones and tissue. It's estimated that around 30 to 50 per cent of people over 60 suffer from it.'

Helping others is an important motivation, says the scientist. That's the reason he wanted to become a doctor as a child. 'In the end, I went in a more technical direction. But I still want to help others by looking at nature to find technical solutions. I hope that we can manage to take our research one step further in the years to come. By looking at multiple organs simultaneously, such as the heart and the kidneys. At the moment, the focus is often on one body part. But everything in our bodies is connected. We have to look closely at that in our work too. So, when we do something with an organ or replace a knee with an implant, we need to look further and take into account how everything is connected. This is complicated, but also very interesting. We've still got plenty to learn.'

FUTURE RESEARCH

The spotlight in this Fundament magazine is on 15 researchers who have been working on their research at TU Delft for some time. But positions are still being filled and so new researchers are starting each month. Who are our newest talents and what will they be focussing on?

BRAM VAN DEN EIJNDEN
SOIL MECHANICS

'I will conduct research on geotechnical uncertainty quantification, ranging from the characterization of uncertainty in lab and site investigation data to geotechnical reliability analysis.'

'The outcome of my research will contribute to novel stochastic techniques in geotechnical modelling and to the uptake of reliability-based methods in geotechnical engineering practice.'

LAURA STANCANELLI
FLUID DYNAMICS AND SEDIMENT TRANSPORT IN HUMAN-INFLUENCED MARINE, INLAND AND URBAN WATER SYSTEMS

I will conduct research on river engineering, tackling interdisciplinary issues related to aquatic ecosystems that span traditional subject boundaries of environmental engineering and ecology.

The outcome of my research will contribute to our understanding of flow-organism interactions and behavioural responses to natural and anthropogenic impacts.

ORIOL COLOMÉS GENE
FLUID STRUCTURE INTERACTIONS FOR INFRASTRUCTURE AND FOR NATURE BASED SOLUTIONS

'I will conduct research on novel numerical methods for problems involving fluids interacting with structures, with especial emphasis on flows with moving interfaces such as ocean waves interacting with energy harvesting devices.'

'The outcome of my research will contribute to the development of digital twins of ocean energy technologies by enabling real-time simulations of multi-phase fluid-structure interaction phenomena.'

JOSÉ ANTONIO ALVAREZ ANTOLINEZ
FLUID STRUCTURE INTERACTIONS FOR INFRASTRUCTURE AND FOR NATURE BASED SOLUTIONS

'I will conduct research on nature-based solutions for coastal resilience using emerging technologies: a highly innovative concept that is based on tailored-Artificial Intelligence, physical systems knowledge, monitoring, and modelling.'

'The outcome of my research will contribute to enable adaptation of coastal communities to climate change through sustainable development, engineering and management of coastal zones, by global upscaling of nature-based solutions.'

TON STEFAN VAN DEN BREMER
FLUID DYNAMICS AND SEDIMENT TRANSPORT IN HUMAN-INFLUENCED MARINE, INLAND AND URBAN WATER SYSTEMS

'I will conduct research on transport processes in coastal seas, focussing on the role of surface and internal waves and with application to, for example, marine pollution.'

'The outcome of my research will contribute to improved modelling of transport of marine pollution including plastic and salvage of, for example, shipping containers, and search-and-rescue missions at sea.'

IURI B.C M. ROCHA
COMPUTATIONAL MECHANICS OF MATERIALS

'I will conduct research on novel high-fidelity computational mechanics techniques for predicting the behavior of high-performance materials and on making these techniques as efficient as possible with the aid of Artificial Intelligence (AI).'

'The outcome of my research will contribute to unravelling how material behavior at very small scales influences the behavior of very large structures, allowing a shift to a sustainable structural design paradigm based on virtual material testing.'

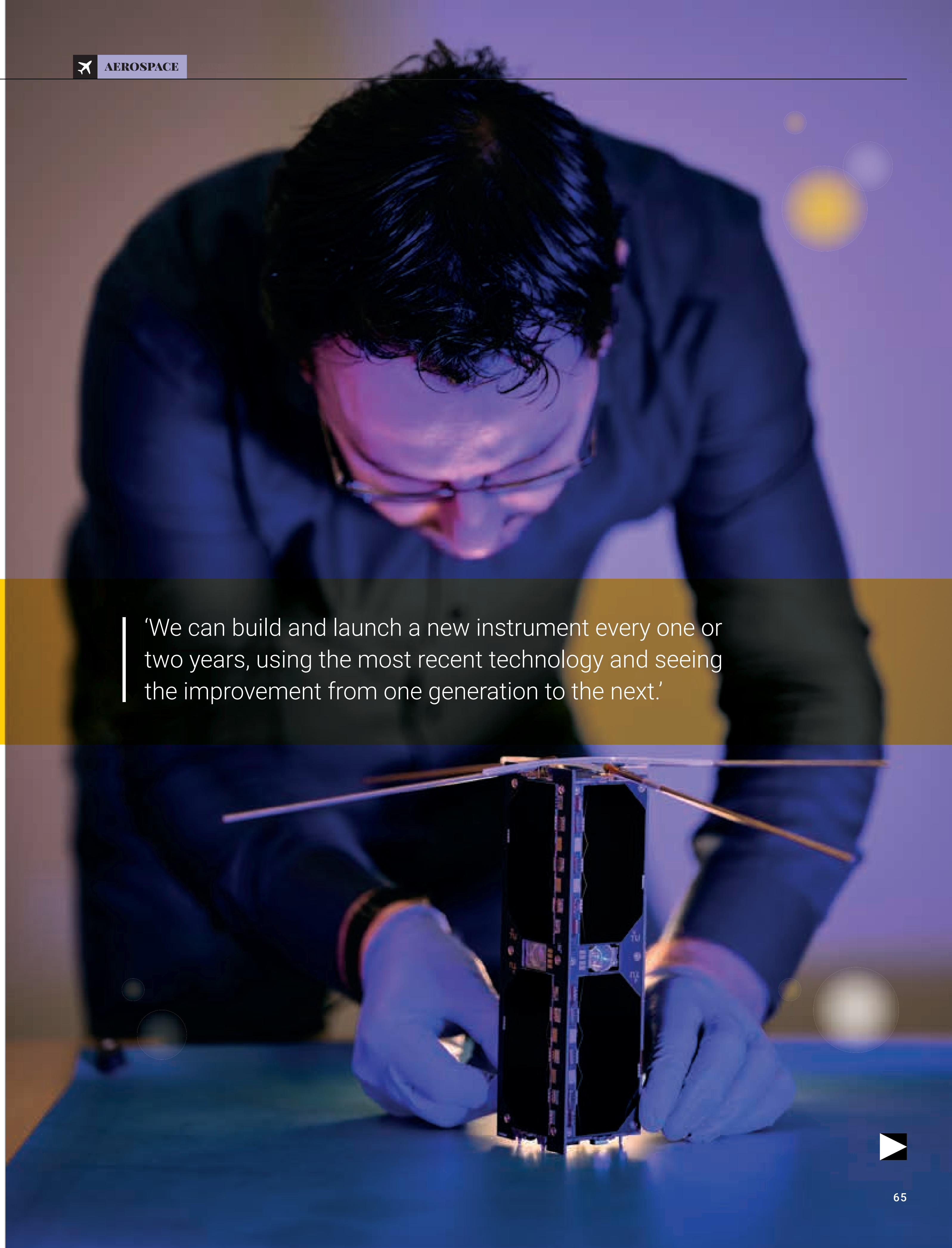
It doesn't sound very elegant, launching a bunch of satellites into space only to have them plummet back to earth. But, while falling, they will map the density of earth's atmosphere – our shield against meteoroids and space debris. It also involves a level of autonomy and coordination that are essential for next generation earth observation technology and future deep space missions.

Flinging tiny autonomous satellites at earth

When the MIR space station decayed into earth's atmosphere over the Pacific Ocean in 2001, its debris was calculated to cover an area 1,500 kilometres long and about a hundred kilometres wide. 'Should this controlled descent, due to some technical malfunction, have happened over Europe, you would have had to evacuate an entire country,' says Stefano Speretta, assistant professor in the Space Systems Engineering group at TU Delft. 'This large uncertainty in where objects falling from space will come down is a consequence of small variations in the density of the atmosphere. These happen naturally because of air currents.' Using balloons and sounding rockets, scientists have been able to build accurate models of the lower atmosphere. Very high up, satellites have been operating for a very long time, providing valuable data on atmospheric density. But very little is known about the region between an altitude of one hundred and three hundred kilometers. Thanks to continuous developments in nanosatellite technology, it is now possible, and affordable, to measure this density in great detail.

Chasing satellites

In the early days of nanosatellites, people were satisfied when they could demonstrate that they work and can do something useful. But now that more than a thousand of such satellites have been launched into space, they have more than proven themselves to be up for real scientific conquests. With his



> 'We can build and launch a new instrument every one or two years, using the most recent technology and seeing the improvement from one generation to the next.'

'can do' engineering attitude and having been involved in roughly twenty-five of these missions, Speretta knows how to push the limits of this technology to help resolve major scientific problems. 'We are developing a concept based on satellites chasing each other through earth's atmosphere,' he says. 'While decaying over three to six months' time, their airspeed is continually affected by atmospheric drag. This, in turn, is directly related to atmospheric density.' A pair of big, expensive spacecraft would need propulsion to prolong their descend and, thereby, the time that scientific data can be acquired. Having the size of a soda can and by relying on commercially available electronics, Speretta's proposed nanosatellites are both cheap to build and to launch. 'Sending multiple pairs sequentially allows us to monitor the atmosphere for a much longer period of time, at a much lower cost.'

Like a rubber band

Here on earth, a single satellite would actually suffice as its absolute position and speed can be determined using the global positioning system (GPS). But Speretta, an avid lover of Star Trek, always has deep space in mind. 'On another planet, such as Mars, you do not have the benefit of absolute position measurements. Using two satellites, or multiple pairs, all that matters is their relative position, the distance between them. This can be measured using a radio link or by using a laser and mirrors.' To ensure proper communication and coordination between the satellites, they should retain a reasonable distance with respect to each other of somewhere between ten and fifty kilometres. The satellite that is moving too fast may for example change its attitude with respect to the direction of motion, increasing its drag and thereby slowing it down. Once it comes too close, the satellites may need to swap this strategy. 'It is like building a rubber band between them,' Speretta says. 'We want the satellites to be completely autonomous in coordinating their relative position. Even here on earth we may not have sufficient time for a manual intervention, let alone when they are deployed in the atmosphere of another planet.'

> 'Small variations in the density of our atmosphere lead to large uncertainties in where objects falling from space will come down.'

Big science with many small satellites

The mission is a good example of what is called a distributed system. It is the next big thing for both deep space and orbital applications and a specialisation of Speretta. Large systems, like the Hubble space telescope, have certainly earned their place in space as they have unique capabilities such as a very high resolution. But as they are not allowed to fail, they need a lot of redundancy which increases their complexity, cost and development time. 'You may eventually launch a large satellite using technology that is twenty years old,' Speretta says.

The alternative is to distribute the instruments and tasks over multiple much smaller satellites, even counting on some of these to fail. These distributed systems need to be able to keep their formation, as it yields the 'stereo vision' that is important for a lot of applications – from geolocation to radio astronomy. But by dividing the risk and tasks, each satellite can be much simpler, smaller and cheaper, drastically shortening the development cycle. 'We can build and launch a new instrument every one or two years,' Speretta says, 'using the most recent technology and seeing the improvement from one generation to the next.' He likes to bring students aboard in these developments to teach them much needed practical experience. 'As the master track is two years, they can basically follow an entire design cycle from beginning to end. Best of all, they get to reach into space.'

> 'Distributed systems are the next big thing for both deep space and orbital applications.'

STEFANO SPERETTA
Assistant Professor
Distributed Miniaturized Instruments for Space

Living on the edge

Rajendra Bishnoi was already working in semiconductor industry, designing hardware for computer chip memories, when he started wondering 'What's next? What's more interesting, more challenging?' These questions eventually led him to Delft, where he now works on novel technological concepts for so-called edge devices, and inspires students to follow his example. 'Conventional computing platforms will start using too much energy soon. We need to look for more energy-efficient alternatives.'

Victorious artificial intelligence

We're getting smarter and smarter, Bishnoi explains via Zoom. He isn't talking about us humans, but about computer systems and algorithms. In 2015, in a visual recognition challenge, artificial intelligence (AI) surpassed the intelligence level of a trained human. The next year, the field hit another benchmark when an AI system beat the world champion of the board game Go. However, these advances come at a price, warns Bishnoi. First of all, the victorious AI system used hundreds of central processor units (your iPhone has only half a dozen). It also took a huge amount of energy, equivalent to about a million watt. Bishnoi: 'I prefer to express it in terms of an electricity bill. Getting the AI to play a single game of Go cost about 300 USD.' That bill doesn't even include the data and time it took to train the AI prior to playing.

From centralised to edge computing

This is the main motivation of Bishnoi: 'If we continue on the current path, AI will consume too much resources.' In a world where we want smart devices everywhere, the energy demands are becoming a serious issue. Bishnoi illustrates a possible solution by an example of a smart security camera. 'To do its job, this camera takes pictures and sends them to a central computer, where they are stored and analysed. Based on this analysis, the central computer could decide to ask the camera to move in order to better see a suspicious activity. The data transfer from camera to central computer and back again takes a lot of time and energy. What if we make the camera just a bit smarter so that it can do its own image analysis?' This is the field of *edge computing*, where part of the required intelligence is moved from mega-scale data centres to the edges of the network.

'A memory that would normally take six transistors, now only takes a single transistor plus a memristor.'

> ‘In a world where we want smart devices everywhere, the energy demands are becoming a serious issue.’

Hitting a fundamental limit

While a step in the direction of energy efficiency, edge computing is challenging us to come up with new ideas about computation. ‘If we want edge computing to be a success, we need to create intelligence that is small enough to fit into the edge device, and that doesn’t require a lot of power.’ And even though our smartphones are wonderful examples of how small and powerful “conventional” microelectronics have become, Bishnoi warns that it is become increasingly difficult to keep making them smaller and more powerful. ‘Progress has been slowing down for the past 15 years. As we’re nearing the scale of single molecules, in terms of the processor speed, we are hitting a fundamental limit.’ A the same time, the power required by computer chips is increasing. ‘We need to look for completely different computer chip architectures and technologies.’

RAJENDRA BISHNOI
Assistant Professor
Quantum and Computer Engineering (QCE)

New ways to store data

These “emerging technologies” are a hot topic in computer science. Take, for example, today’s memory chips. They are made of millions of transistors and capacitors, all electronic devices that have been around for almost a hundred years. Bishnoi and colleagues are looking for new ways to store data using so-called memristors, which are tiny electronic components through which small electrical currents flow. ‘These currents depend on the resistivity of the components. As the resistivity can be programmed, a measurement of the current flow works like reading out a memory. This explain the name ‘memristor’, merging the words memory and resistor. As the wire’s resistance doesn’t need any power to keep its programmed state, it is an energy-efficient system. A memory that would normally take six transistors, now only takes a single transistor plus a memristor. Calculations indicate this could reduce energy usage by a factor of 10 to 1000. Even better, memristors allow us to read multiple – we’re currently working on more than 128 – memory positions in one go, which is impossible when using traditional approaches.’

Wearable heart monitor

Bishnoi dreams of developing emerging technologies that can be used for a wearable device that records the electrical signal of your heart in the form of an electrocardiogram (ECG). While smart-watch-based ECG apps are already available, they rely on the energy-consuming paradigm of sending data over the cloud. ‘We are dreaming of a smart-watch packed with AI that is capable of analysing your ECG without the help of a data centre.’ As each individual user has a different heart rhythm, the AI will have a lot of learning to do. ‘To minimise its power usage, we want it to use a spiked neural network. That’s a type of AI that lies dormant until it detects a certain input, after which it springs into action. Such an approach would be very appropriate for an ECG monitor, which only needs to sound the alarm if the heart rhythm deviates from a healthy one.’

Foundations for the future

It’s impossible to predict what types of emerging technologies will eventually make it into production. But, Bishnoi is sure about one thing: ‘In 50 years’ time, anything that can be automated, will be relying on AI. And this AI will surely run on a very different type of computing platform than we are using nowadays.’ The work by Bishnoi and his colleagues is laying the foundations for this future.

> ‘In 50 years’ time, anything that can be automated, will be relying on AI.’

IN SEARCH OF THE PLASTIC SOUP

To better understand the whereabouts of floating plastic soup, you need to investigate how the water moves at different depths. Angeliki Laskari, researcher of Multiphase Systems at TU Delft, therefore studies fluid dynamics, the science of the movement and flow of water. One of her goals is to help predict how plastic spreads in water.

Large pieces of plastic from air mattresses, bags and packaging materials are bobbing around in our oceans. Beneath the surface of the water, they descend in tiny pieces almost like snowflakes. They continue to sink to the dark bottom as they pass colourful fish, enormous turtles and sea cucumbers.

This plastic is causing massive problems. It's polluting the sea and threatening marine life. Fish are eating it, choking on it and getting tangled in pieces of plastic. Waves and currents cause the plastic to travel for many kilometres at rapid speeds. As a result, it can be found almost everywhere. Sometimes it floats on the surface of the water and sometimes it sinks to the seabed. How is it possible that plastic is ending up in so many different places in the water? This has to do with fluid dynamics, the science of the movement and flow of water. Scientist Angeliki Laskari of TU Delft's 3mE faculty is investigating this phenomenon. 'I'm trying to understand the movement of water. So we can predict how plastic is spreading.'

Sunken plastic

That seems simple at first sight. You can see a plastic bag floating on the water, for example. But it's incredibly complicated. Because nothing is easy to predict on water. We're not only talking about large piece of plastic, like bags, but also micro-plastics. Tiny pieces that disrupt marine life. They're carried away by waves, currents beneath the surface of the water. 'The temperature and the presence of bubbles also play a major role,' Laskari says.

'I'm trying to understand the movement of water. So we can predict how plastic is spreading.'

'Sometimes we see a lot of particles in one place. Why is that? That's something we want to find out too. But we haven't reached that point yet. To make a solid prediction, you first need to understand exactly how all those movements under the sea work and how particles react to them.'

'The ultimate goal is to predict where the plastic will end up. When a piece of packaging material blows into the sea in Scheveningen, you know that certain parts of it will end up in Den Helder and others near Dover or even Boston.'

That's why you first need to have solid, fundamental knowledge of how water moves at various depths and also under different conditions. What's the weather like? How warm is it at different depths? What role does turbulence, underwater vortices, play? 'Science has already generated a lot of knowledge, so we have developed ideas about this. But we're not there yet. We still need to further improve our understanding. Particularly regarding movements under the surface of the water. For example, when plastic has sunk.'

Particles in a pipe

Laskari conducts many experiments in the lab at the 3mE faculty. She looks at flows that not only contain water, but also bubbles and small particles. 'We want to know how all of this moves under different conditions. If you shine light on it, you can barely see through the particles. That's why we measure what happens with ultrasound. You can compare this with the technology used to create images of babies in the mother's womb. We use similar technology to visualise how everything moves in the pipe.'
It's difficult to interpret these images with the naked eye, however. Everything is constantly moving in the water: all kinds of particles of different sizes, as well as air bubbles. 'That's why we're using an algorithm, a calculation program that monitors how everything has moved. This allows us to see the speed, height and concentration of particles.'
The ultimate goal is to predict where the plastic will end up. When a piece of packaging material blows into the sea in Scheveningen, you know that certain parts of it will end up in Den Helder and others near Dover or even Boston. 'Sometimes we see a lot of particles in one place. Why is that? That's something we want to find out too. But we haven't reached that point yet. To make a solid prediction, you first need to understand exactly how all those movements under the sea work and how particles react to them.'

Playing with water

This fundamental knowledge can lead to even more applications. For floating solar panels, for instance. 'They're placed on flexible structures so they stay afloat. I'm examining how they react to waves and the currents beneath them. Here, too, we want to predict how the solar panels will react to the water in different weather conditions.'

This combination of fundamental research, which examines how something works, with practical applications appeals most to Laskari. 'It gives me great satisfaction to know that my work is socially relevant. I want to do my part and contribute to something that makes the world a better place. At the same time, I find it fascinating to discover exactly how things work. That's why the fundamental side also appeals to me.'
It's no coincidence that Laskari is working with water. She's from Greece, where she spent summers on Serifos, one of the country's many islands. 'There was water everywhere. My father had a small boat and we often went sailing in it. I played near the sea almost every day. One of the reasons that I love living in the Netherlands is that there's water everywhere here too.'

So it's a subject that has a firm hold on her. 'It still makes me curious. Water is never boring. It's constantly changing. That's why it's so difficult to predict, because you have to study everything you want to say about it very carefully first. In fact, that's why the subject still has my attention.'

ANGELIKI LASKARI
Assistant Professor
Multiphase Systems

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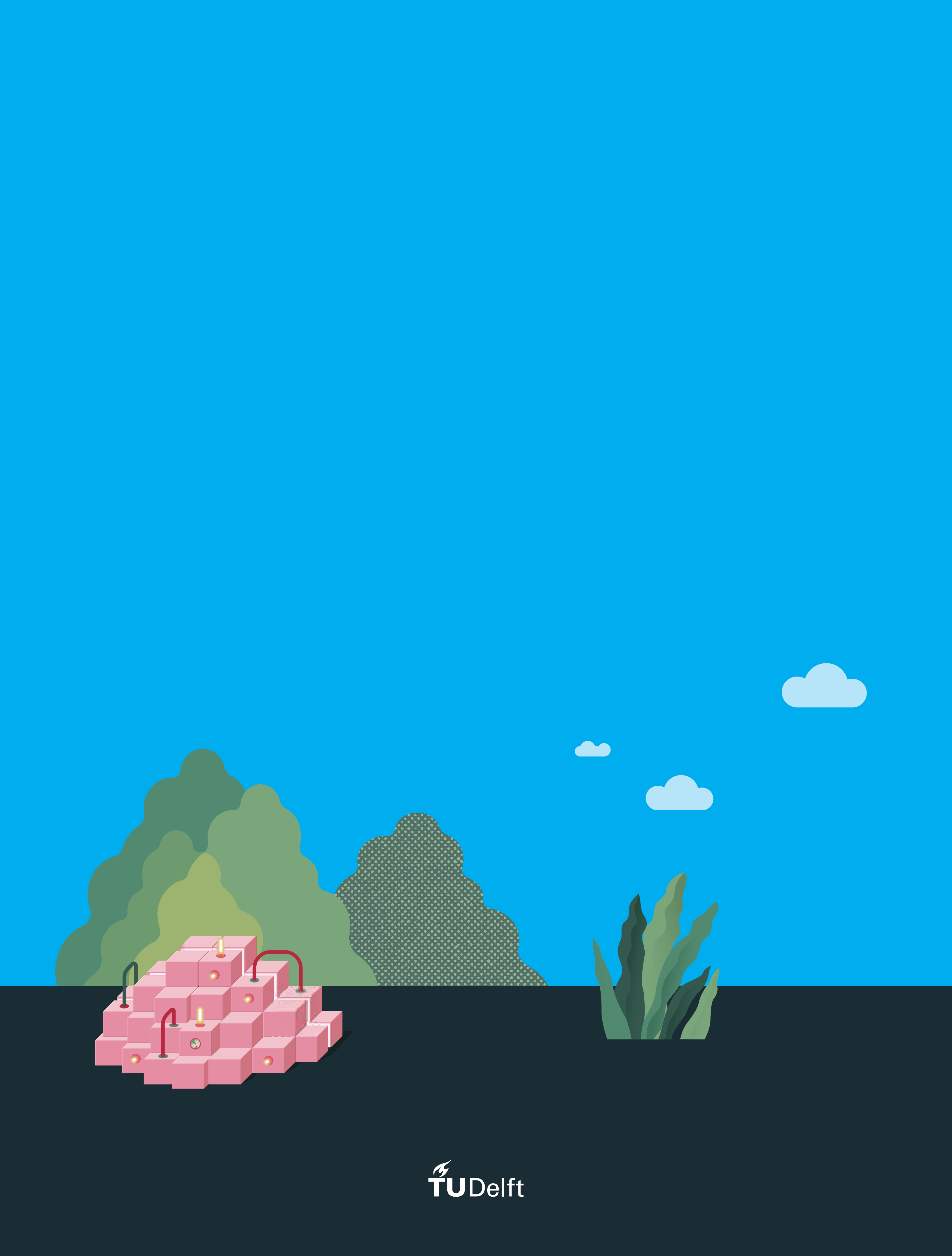
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