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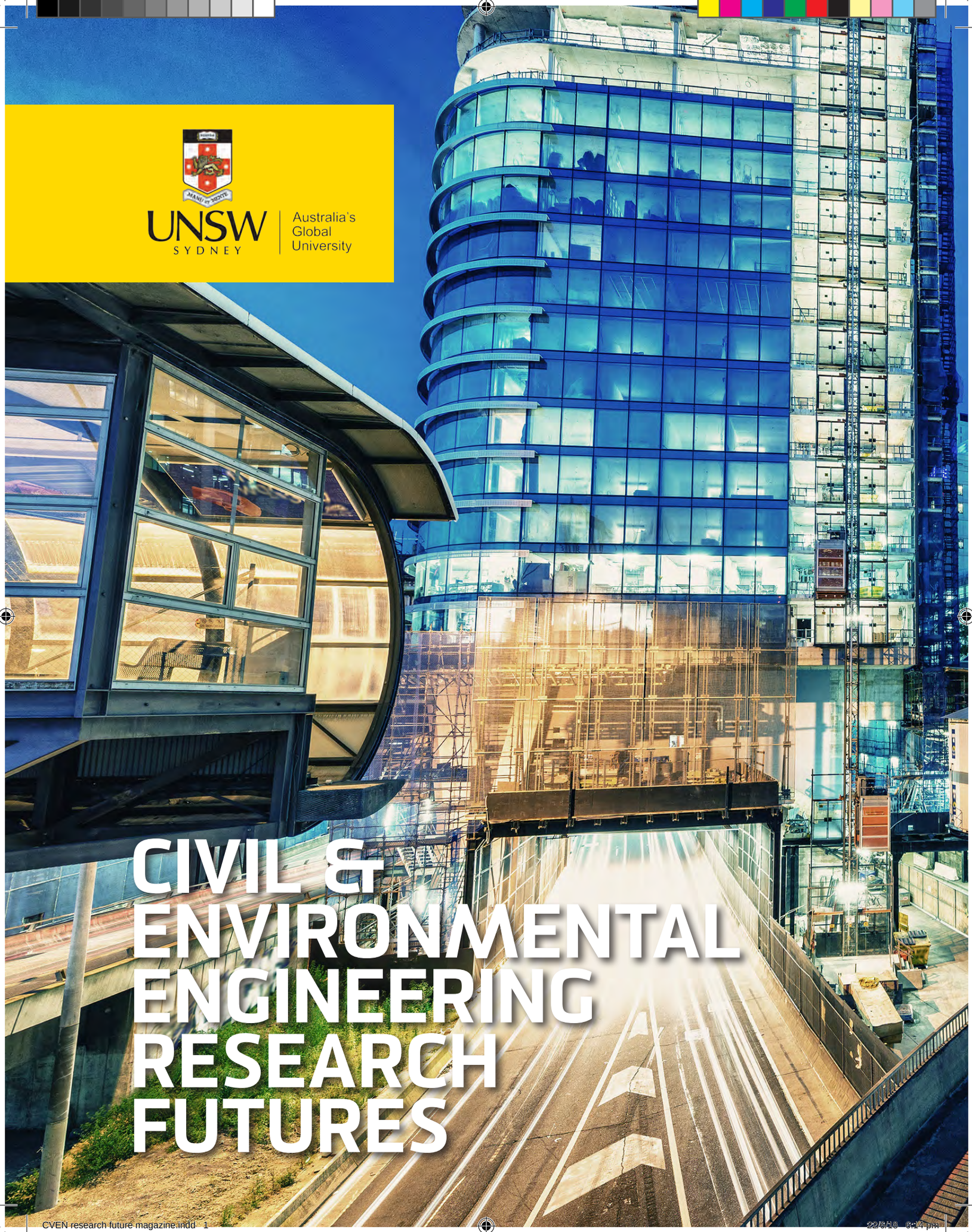

CIVIL & ENVIRONMENTAL ENGINEERING RESEARCH FUTURES

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ABOUT US

THE UNSW School of Civil & Environmental Engineering is internationally ranked by AWRU and QS World University Rankings as the premier School of its kind in Australia and as one of the world's top twenty.

The School is committed to advancing a more prosperous, safe and just society. Our courses emphasise sustainability and a consideration of engineering impacts, with an integrated and inter-connected view of the world. We continue to forge ahead with innovative research fields, new educational courses, and an ever expanding network of industry connections.

Our Centres and discipline groups provide focal points for our eighty researchers to contribute to global efforts in innovative civil, environmental and geospatial engineering research. We have a five out of five research ranking from the Australian Federal Government (ERA) and have won over 150 highly sought after Australian Research Council grants and fellowships. With strong interdisciplinary and external industry collaborations - and with mentorship provided to our great young researchers – we aim to continue our leadership in research and teaching excellence.

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WELCOME

WELCOME TO this special research futures edition from UNSW Civil & Environmental Engineering (CVEN), profiling just some of the amazing work being undertaken at the School by our globally acclaimed researchers.

Our School is at the forefront of civil, environmental and geospatial engineering research, working annually with over 100 industry and government organisations. Indeed, the importance we place on the movement of our research to industry practice cannot be overstated.

This booklet is the outcome of a recent research industry futures forum which the School hosted in Sydney. Engineers, scientists, managers and policy makers from forty five organisations, ranging from small innovative start-ups to global engineering companies, as well as local and state government, came together with our researchers to listen, share and sometimes argue, on the contemporary hot engineering topics of smart cities, resilient communities, disruptive technologies, and sustainability and social justice.

Our aim with the Forum was not just to share our capabilities and achievements, but to listen to industry needs, and to explore together future challenges, possible solutions, projects and ongoing relationships. We believe that industry and universities have extensive opportunities to work together in the coming years, particularly as new technologies change existing engineering and manufacturing practices.

This booklet shares some of our research insights and visions for local and global futures in construction, environmental, geospatial, infrastructure, transport, and water engineering in the new digital, disruptive diverse world.

Professor Stephen J Foster
Head of School

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TRANSPORT FUTURES

SAME, SAME BUT DIFFERENT?

rCITI leaders: A/Prof Vinayak Dixit and Prof Travis Waller – *It is only when you put a number on an issue that you can enact real change*

MOBILITY IS at the heart of transport engineering. To get to where we want to go swiftly, easily, efficiently and sustainably seems to have become an inalienable right in the modern world.

Maybe it has always been so. Iron age humans no doubt wanted to travel with speed and safety to attain food and tools, to gather with others and to explore. The need to move freely is fundamental to our existence on this planet and as true in a village in rural India as it is in any modern city. But regional, historical and wealth distinctions become apparent in accessibility to modes of travel and available technologies.

So, while our basic needs may be the same across time and space, transport in an urban centre like Sydney is going through widespread and fundamental change, the like of which has not been seen for over a century.

Advisian Professor of Transport Innovation Travis Waller articulates some of the challenges facing the profession in the midst of such rapid transformation: “We currently have disruptive technologies, big data, autonomous vehicles, electric vehicles, alternative fuels, shared economies, connected travellers, connected vehicle fleets, on demand public and private transport, subscription cars all happening at once.”

As the transport domain changes, engineers must let go of historical assumptions. No longer are travellers confined

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> "No longer can we assume that public transport is a government delivered service with public good and system optimisations as its main objectives."

to a limited range of transport modes. Historically it has been a question of I own a car or I don't. Now we move between modes more fluidly. Maybe I subscribe to a car, only using it for critical trips, while at other times I cycle or take a bus. As Waller says, "Individuals are changing how they travel, but it is government and engineers who need to plan around that highly disruptive and ever-changing reality. A daunting task, but an exciting one for researchers."

No longer is transit design built solely around physical stations and stops. Here is the bus stop and there are only a few of them. Now with smart phones and on demand transit, any intersection becomes a virtual bus stop. Scheduling and servicing design needs to accommodate a changing and fluid on ground reality.

The contemporary reality is that everyone carries a data generating and receiving device. This has many implications, some of which have recently emerged, some yet to be understood. We have so much information, yet this is not a cure-all.

"I receive, through my smart phone, transport information that is reliable and correct, so, I become a better self-optimiser, better at finding a quicker, smoother, less crowded ride," says Waller. So far, so good. When self-optimisation aligns with system optimisation that is indeed a wonderful thing. But when it differs it causes confusion. So how do engineers design a reality that aligns self and system optimisation, where the self-optimiser still helps the system? "This can be achieved," says Waller, " through effective development of algorithms, route and city design, quantitative tools and behavioural incentives, such as reduced pricing, that create right behaviour for the system as a whole."

No longer is transport modelling about average conditions: "This is not what people care about. We did that historically because we didn't have data. Now GPS means we can have second to second data about individual trips."

No longer can we assume that public transport is a government delivered service with public good and system optimisations as its main objectives. Vinayak Dixit, Deputy Director of UNSW's Research Centre for Integrated Transport Innovation (rCITI) believes this shift has huge implications. "If service mobility is now being provided by private players, then researchers and government need to ensure fairness of distribution and accessibility so that more mobility deserts do not appear. The complex relationship between transport and the property market needs to be analysed and factored into decision making."

So many questions. How is technology interacting with humans? How is our behaviour as travellers changing? How are networks altered by these changes? What do we value as a society? Is it more important to get to work quickly or to be energy efficient? Is traffic flow more important than trees? Is efficiency more important than sustainability?

These are not either/or propositions, but questions that reside on a continuum of relative values: values that must be incorporated into transport modelling and planning. Tricky, delicate, time consuming.

While democracies at large must define these values, transport engineers must put numbers to these qualitative issues. As Travis Waller says "It is only when you put a number on an issue that you can enact real change. Quantitative data must be used to augment and improve survey information, but we must be careful not to let sheer volume overwhelm a balanced approach to research data."

New operational paradigms require innovative data ex-

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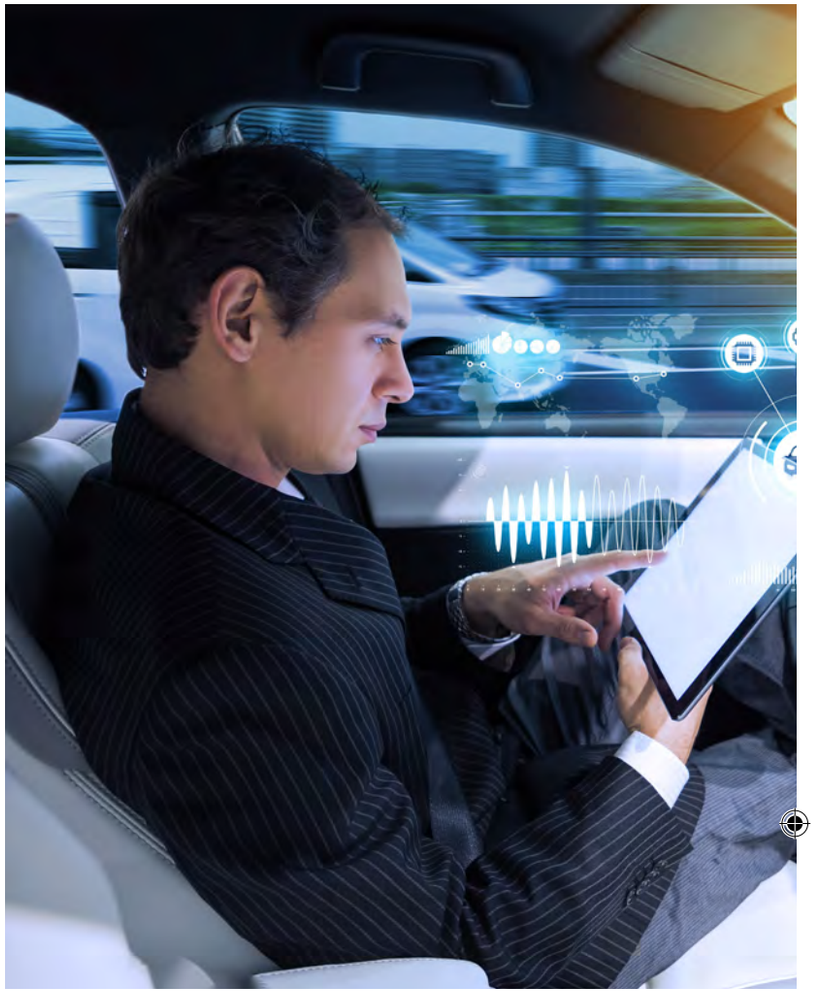
“We currently have disruptive technologies, big data, autonomous vehicles, electric vehicles, alternative fuels, shared economies, connected travellers, **connected vehicle fleets, on-**demand public and private transport, subscription cars, all happening at once.”

cavation and processing. In partnership with Google Maps Outreach Grant, rCITI is investigating emerging data sources. With access to Google data bases around the world, rCITI can create analytical profiles which are aligned with information from social media. “Someone sends a tweet. We can pinpoint an exact where and when, while LinkedIn provides socio-demographic information about that traveller, which is vital for regional planning,” explains Waller. “Looking across social media we can paint a much broader picture than our historical perspectives gleaned from surveys because they provide revealed outcomes.”

As we step fully into this new age of meta data, universities can take a leading role in the ethical implications of change. rCITI’s Vinayak Dixit has, for years, been advocating for data ownership and privacy rights, receiving enthusiastic support in theory, but only limited support in reality. “Universities demand a rigorous ethics approval process around research and we could be leaders in this area.”

And not only in this area. If so many of our historical engineering tools no longer apply, what do we replace them with? No-one has that definitive ‘something’ yet. But that’s the point of engineering: solve problems today and build tools for the future.



WHOSE HANDS ARE ON THE WHEEL?

DRIVERLESS CARS

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ASSOCIATE PROFESSOR Vinayak Dixit makes relationships a priority because he believes that it is through the inter-personal that innovations are created.

In 2013 with funding from the Australia Research Council (ARC), rCITI, CVEN's transport research hub, created TRACSLab. Already a world leading facility, housing multiple driving simulators networked together, with the ability to connect to traffic microsimulation software, TRACSLab recently formed a field-leading, inter-university relationship with the University of Sydney to investigate the travel behaviour of driverless automated vehicles (AVs).

Funded by insurance industries and transport authorities, Vinayak and his team are asking some fundamental questions raised by AV travel. In AVs, how do people behave? What kind of choices do people make when under risk or uncertainty? How is it to come in and out of autonomous driving? What can a driver do while being in a driverless car? Seated in the TRACSLab driving simulators, drivers in a virtual reality, reveal and record the answers to these questions.

There is still the battle of perception. Incidents involving AVs receive a disproportionate amount of media coverage, which results in a distorted perception of how dangerous they are. "The dangers of AVs are similar to regular vehicles, but often, traffic around an AV on-road become distracted and fearful. AVs are often involved in accidents they have not caused."

As a committed researcher Vinayak Dixit sees every AV accident as an opportunity for new questions and deeper discovery. "This technology is based on the interaction between the AV and an individual. Currently, an AV finds it difficult to 'understand' intent as a human would, because the information exchange between humans is evolved. How could we program this kind of evolved intersubjectivity into an AV?"

Until that time, there are precautions we can take to maximise safety. "One response is to clearly identify AVs to onlookers with improved signage. Just like an L plate or a P plate we need an AV plate. Human behaviour then starts to change because our understanding of the risk associated with an AV becomes part of the interactive relationship and assists in that evolution we need for wide civic application."

There is also the barrier of price, as AVs are still in the experimental and very expensive stage. One further and very basic challenge to the driverless car is why do we need them? Productivity is the 'driving' force for industry and for us city folk sick of wasting our time in traffic. "This technology is about removing human effort, frustration and loss of time around travel, which are all extremely unproductive."

Then there is the potential for an increase in traffic safety. While this runs at odds to perception, driverless cars will eventually reduce accidents caused by driver fatigue, speeding, inattention and distraction because so much more data is feeding into the car, like the full 360 degree view and the ability to track multiple objects.

Perhaps most rewarding to researchers like Dixit would be the potential of AVs to provide mobility for those who have none or are limited by age or disability. Technology that serves this kind of human freedom is worth pursuing. Dixit knows that driverless cars are a frontier many do not want to cross. But he is a patient researcher. "30 years ago, we accepted auto pilot on planes. Pilots used to make an announcement. Now it is completely accepted as the norm. 85% of flying time is in auto-pilot mode. At our ports, in manufacturing and mining, AVs are common. Perhaps it is just a matter of time for driverless cars."

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ON-DEMAND TRANSPORT

CHANGING HOW WE MOVE

WE LIVE in a world of on-demand services. Hungry? Order delivery through Foodora or Menulog. Need to go somewhere? Call an Uber. In many ways, personalised services like these have become part of the way we live.

But what if we could apply on-demand principles to big – and complex – public services? Imagine using an app to summon a bus, for example, rather than waiting at the bus stop at a scheduled time. According to Dr David Rey, a researcher at the Research Centre for Integrated Transport Innovation (rCITI) at UNSW, it's already happening. An expert in operations research, a field of enquiry that spans applied mathematics, computer science and economics, Rey has been applying his expertise to a series of on-demand public transport projects.

"On-demand transport is a user-driven approach to public transport that does away with traditional transport routes and schedules," he says.

"Instead, passengers request transport to a specific destination and are collected and dropped off at connected, easy-to-access locations at a time that suits them."

Recently, Rey has developed routing and scheduling algorithms for leading transport organisations to demonstrate how on-demand transport could work in a range of different scenarios. He says that from a public transport perspective, on-demand transport initiatives are about providing better customer service by optimising the allocation of available resources.

"If you sit on an empty, hour-long frequent bus, you're going to have a long travel time. An on-demand service could cut down the journey and get you there much faster without necessarily impacting service costs."

Rey has also worked in the challenging area of customer acceptance, investigating customer attitudes towards new on-demand transport models. Unlike traditional modes of public transport, where passengers play a passive role (waiting at an assigned location at an assigned time to connect with the transport system), on-demand models active engagement with the transport experience, with tools like smartphone apps and call-in services being used to book a ride.

> "The idea is to make better use of what we have."

"I've helped organise surveys and analysis on the concept of on-demand services. In the context of on-demand transport as a new offer that nobody has experienced before, what is the propensity of people to change and leave their car at home, for instance, and take an on-demand vehicle?" he says.

While some projects have focused on small populations, others deliver a rationale for on-demand transport as part of a multimodal transport network in major metropolitan centres. And it's a rationale that bears weight: as well as reducing transport costs and enhancing the passenger experience, on-demand transport has an important role to play in improving traffic flows and enhancing access to, and use of, critical transport infrastructure like roads.

"The ultimate goal of on-demand transport, whether it's public or private, is to reduce the numbers of cars on the road and to make better use of existing infrastructure – it's not about building new roads or adding new vehicles," Rey says. "The idea is to make better use of what we have."

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INTRODUCING

BIO-SECURE MOBILITY

Dr Lauren Gardner's work is so unique she has developed a new discipline to accommodate it. Bio-secure Mobility is at the crossover between engineering and public health.

AS THERE wasn't really a way to describe the type of research I'm doing, my colleagues and I have coined a new phrase," explains Dr Lauren Gardner, whose multiple research interests have recently been drawn together into a fascinating new field.

"We're calling it Bio-secure Mobility and it explores how people and things moving around our globalised world spread infectious disease. This includes the spread of naturally occurring viruses or malicious manmade biosecurity threats," she says.

As a Senior Lecturer in the School of Civil and Environmental Engineering, a member of the Research Centre for Integrated Transport Innovation and a Research Fellow with the Faculty of Medicine, Gardner says her interests sit at the point where engineering and public health merge.

"I use my background in network modelling, i.e. the connectivity of transport systems across all different modes and scales, to try to understand its implications in the public health space, specifically around epidemiology," Gardner continues and goes on to explain that Bio-secure Mobility has three key research goals that span both understanding the spread of a particular outbreak and mitigating the risks it poses.

The first goal is gaining a clear understanding of how things spread through a network and might result in the creation of what Gardner calls a 'diffusion model'. "If we know how things are connected and how people move around, we can model how something might spread. For example, we might look at how the flu would spread through Sydney's population, or how the Zika virus spread from Brazil to the rest of the Americas," she says.

The second goal is about gaining a clear understanding of the different factors that contribute to the risk of spread. "What is pushing the disease through the network?" she continues. "Is it people moving or are there other more significant local factors at play, such as population density, land use characteristics, climate characteristics and infrastructure characteristics?"

The third piece of the puzzle, explains Gardner, is about control. "If we have answers to the above two goals then we can get smarter about allocating resources to try and stop spread."

With a focus on the practical, Gardner says the outcomes of her research might include a series of tailorable methodologies or models that can be broadly applied and adapted for use in a real-time decision-making setting. "If there is a sudden outbreak of a new virus, we want to be able to provide public health policymakers with a tool so they can make smarter decisions about how to control and mitigate the risks of the outbreak."

Ambitious in its scope, the questions raised by Bio-secure Mobility rely on multidisciplinary collaborations between engineers, biologists, entomologists and public health professionals in addition to requiring huge amounts of data. "Data is both our biggest challenge and our biggest opportunity and we need huge datasets that capture human mobility, real-time outbreak status, socioeconomic factors and environmental conditions," Gardner says.

In our increasingly globalised world, where international travel has become so necessary and so prolific, Gardner's research acknowledges this huge space where things like human mobility, climate change, and urban and rural land use changes can have grave and swift implications in terms of disease spread. It is a timely reminder of how susceptible our world is to these kinds of risks.

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QUANTIFYING UNCERTAINTY

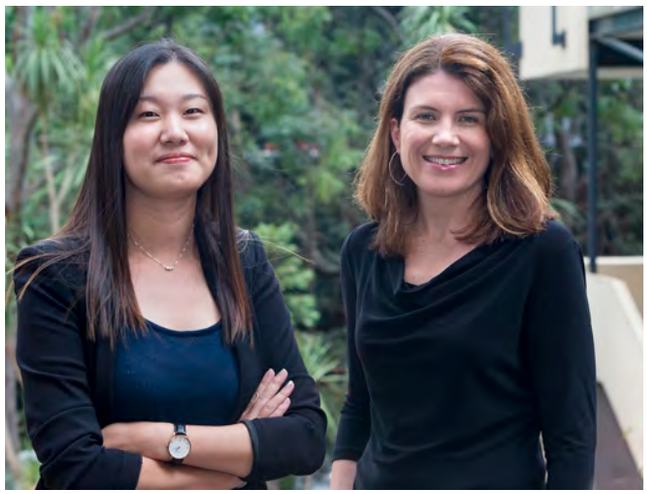
THE MATHS BEHIND FUTURE PROOFING OUR WATER RESOURCES

'VE ALWAYS been fascinated by what we don't yet know about engineered or natural systems," says Associate Professor Lucy Marshall, Deputy Director of the UNSW Water Research Centre (WRC) "particularly in water resources. Analysing our uncertainties means I get to come to work every day and learn something new."

The central interest in all of Marshall's research is 'uncertainty quantification'. Much of her research is structured by a formal probabilistic approach known as Bayesian inference. "It is an elegant statistical technique that brings together two types of information; data or observations from the field and expert knowledge or 'prior information'," she explains. "The prior information provides a researcher with probability distributions informed by scientific or specialist knowledge, beyond what is explicitly observed. Informative priors can provide us with a lot of information, while non-informative priors have higher levels of uncertainty."

Bayesian methods have been used across many disciplines, but it is the discipline of hydrology that has especially embraced this elegant statistical approach, fostering its expansion and development for environmental modeling. Lucy Marshall and her ARC team: Dr Hoori Ajami, Dr David Nott and Dr Yating Tang are players in a burgeoning and lively debate about modelling methodology. "The Bayesian approach," Marshall notes, "is particularly useful as we can attribute uncertainty to field data errors, a lack of expert knowledge, or model biases."

As a newly ARC funded Discovery Project, "Advancing uncertainty quantification in terrestrial hydrologic systems" the work is to develop Bayesian methods specifically using Approximate Bayesian Computation (ABC). The distinction between ABC and a traditional Bayesian approach is that in ABC there is no requirement to formulate a 'likelihood' or statistical measure of the merit of the model. Instead a series of simulations are created and then selected on how they correlate with data. "It is an easy, robust and mathematically sound way to estimate error. It is particularly suited to complex error structures."



As easy as ABC: Exploring Approximate Bayesian Computation: eco-hydrologists Dr Yating Tang and A/Prof Lucy Marshall

ABC is a relatively recent development in Bayesian modelling and Associate Professor Marshall is at the forefront of ABC research. Her 2012 co-authored article "Generalized likelihood uncertainty estimation (GLUE) and approximate Bayesian computation: What's the connection" was the first ABC hydrology article to be published. "These ideas have been percolating for several years, so I am very excited about this ARC project. We aim to demonstrate just how powerful ABC is, as it has, perhaps, been underestimated until now."

A year into the three-year project and Lucy is very pleased with their progress and outputs. In 2017, using long term data sets, the team has established baseline ecohydrological models and a foundational Bayesian framework for calibrating these models. A first journal article has been published titled "A Bayesian alternative for multi-objective ecohydrological model specification". A second is being created now, deeply influenced by the peer review process of the first article. Lucy Marshall pays homage to this process as part of any ongoing research project. "We received incredibly learned and helpful

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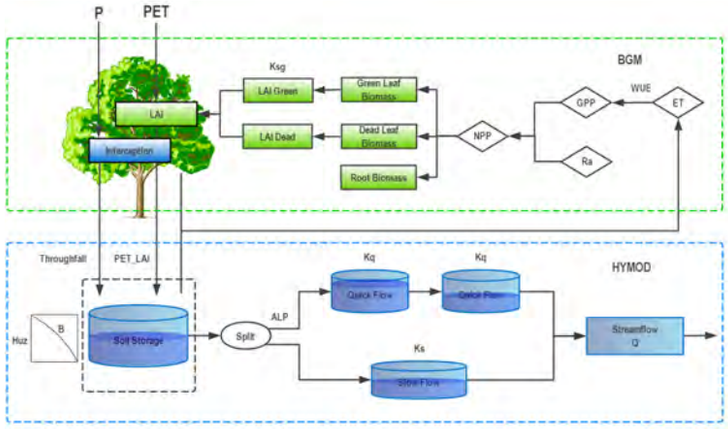

Ecohydrology combines water and streamflow data with vegetation dynamics data

critiques, especially in the area of data quality. So, our second paper will investigate satellite data errors, including an established Bayesian approach to precipitation errors. Understanding the extension of Bayesian methods into ecohydrology has been exciting."

In 2018, this ARC team will establish and complete an appropriate ABC framework and will use this framework "to investigate errors associated with our assumptions about model selection." More publications will follow as Lucy and the other team members move closer to fulfilling the overall ambitions of the project. "We aim to characterise the importance of input errors in models and to more fully understand how uncertainty in rainfall and evapotranspiration is affecting the overall model. A working ABC framework will make it much easier to characterise what these data errors are."

Developing Bayesian and Approximate Bayesian methods is not the only aspect of Lucy Marshall's research that is innovative. Over the last decade Lucy's interests have been shifting away from purely engineering/hydrological perspectives to the broader field of ecohydrology. This is a relatively new and expanding field that, according to UNESCO, "attempts to reverse the degradation of water resources and stop further decline in biodiversity by utilising our growing understanding of relationships between hydrological and biological processes."

Lucy was immersed in this kind of relational thinking during her eight years spent as professor in the environmental science department at Montana State University. "There was much more emphasis on natural resources in this department and this altered and expanded my engineering focus on models as problem solving tools. I began to link my research more deeply with the actual physical systems, working more collaboratively with people in the field. In a way, my time at Montana was my second PhD."

Yet don't expect to see Lucy wading through rivers anytime soon. "I know where my strengths lie, and my great love, from a very early age, has always been mathematics." Marshall believes that the creative potential of higher level mathematics is largely misunderstood, underestimated or ignored. "We need creativity in mathematics for it to be relevant in a range of fields and disciplines." She attributes her early academic success in the USA to her awareness that mathematical research, handled with artistry, could be widely applicable. She also believes that this adaptability was consciously fostered in the broad-based training she received from CVEN.

> "We can no longer study water in isolation from its environment."

This flexibility is also reflected in the make-up of her ARC team which includes a mathematician, a statistician, an early career eco-hydrologist and an engineering hydrologist. This type of cross fertilisation not only increases the complexity of the input and the subsequent models, but allows these researchers access to knowledge bases, networks and possibilities which would have been unavailable previously.

Ecohydrology creates a natural bridge between engineering and climate change science, increasing its relevance and its capacity to heal the planet. "Ecohydrology combines, in an organic way, water and streamflow data with vegetation dynamics data. In the past the vegetation in a catchment system has often been ignored. But now we are equally concerned with issues such as leaf area indices, evapotranspiration rates, interception and soil moisture dynamics. And if we have a model that incorporates more processes, that has ecohydrological components, then it has the potential to be more robust and more accurate in the face of climatic change."

So the ARC project "Advancing uncertainty quantification in terrestrial hydrologic systems" marries uncertainty quantification, engineering models as problem solving tools and an actual connection to the complex processes of natural ecosystems to achieve a better estimation of just how important rainfall and evapotranspiration are for any workable hydrological model.

"We can no longer study water in isolation from its environment" says Marshall. "To address climate change effectively, any model representing any water catchment system must include possibilities for massive environmental change. It is the only way a model can work now."

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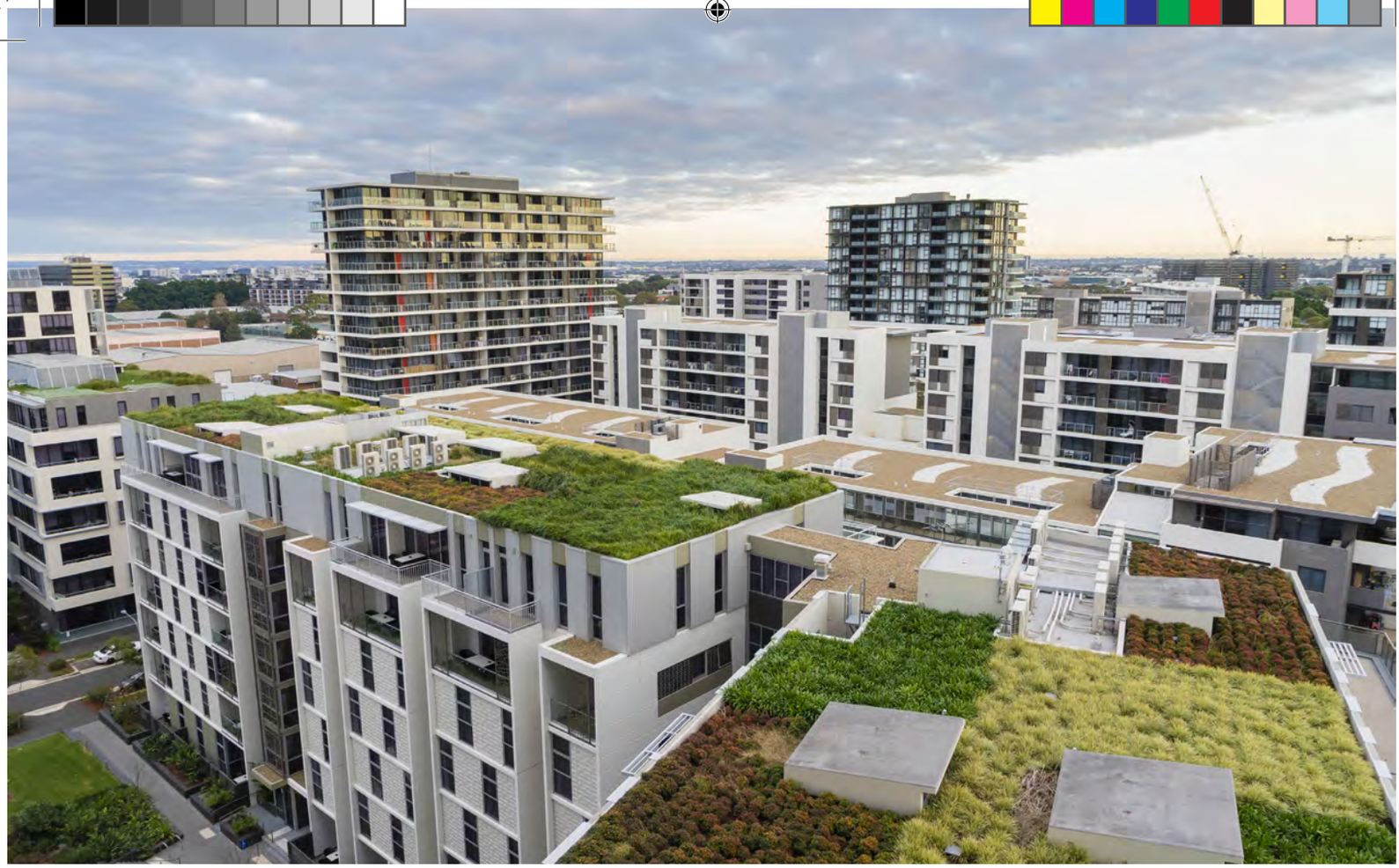

SPONGE CITIES

TRANSFORMING URBAN WATER CYCLE MANAGEMENT

SPONGE CITIES is an urban water management approach that captures stormwater for re-use through detention, infiltration, evapotranspiration, treatment, harvesting and recycling. The beneficial effects are many. It combats flooding, reduces water run-off, reduces urban heat, improves water quality, increases water storage, vegetates the urban environment, increases property values and enhances the quality of urban living. Similar concepts have been employed all around the world over the past 30 years, e.g. in Australia Water Sensitive Urban Design (WSUD), in the USA Low Impact Development (LID), and in the UK Sustainable Urban Drainage System (SUDS). Two things make Sponge City unique. One is the name that describes in simple poetics what it is hoping to achieve: to absorb the water we have previously let escape. Second is the determined and widespread implementation in China, driven by government support. Sponge City is the most holistic plan to date as it includes a whole range of urban water cycle management, not only stormwater, and is supported by strong concepts, broad principles and latest technologies.

The Chinese government sees Sponge City as an alternative to expensive and disruptive retro-fitting of drainage systems. Rapid urbanisation in China has demanded a rapid response. By 2016 Sponge City programs were active in thirty cities, mainly attempting to reduce flooding. Great successes have been achieved, and the country is targeting to achieve 70% of runoff

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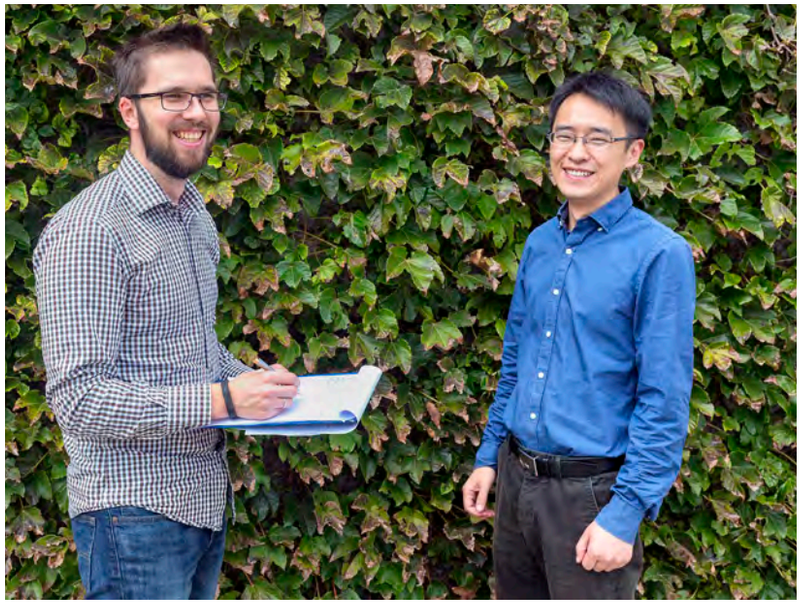

Dr Veljko Prodanovic and Dr Kefeng Zhang (Research Manager), Sino-Australian Centre on Sponge City, Water Research Centre (WRC)

to be adsorbed and reused in 20% of urban areas by 2020, and 80% of urban areas by 2030.

As research manager of the Sino-Australian Centre on Sponge City (SACSC), Dr Kefeng Zhang is responsible for overseeing the direction of one of the leading consulting bodies on Sponge City research and practice. Dr Zhang is an emerging but already highly awarded engineering academic. He has developed the first framework for validating WSUD treatment systems, and has also been involved in development of the Water Sensitive Cities Toolkit (developed through the Cooperative Research Centre for Water Sensitive Cities) that quantifies the benefits to community and environment of a Water Sensitive Cities approach.

SACSC at the School's Water Research Centre is an international partnership between UNSW, Monash University and EastHigh Environmental Holdings, a Chinese company acting as the implementation arm of this partnership. SACSC is growing at a fast rate, with new research and engineering staff facilitating a constant flow of information between Australian researchers and China. The centre has three main research areas: Green technologies, urban water modelling and novel technologies. Green technologies are visible in any city with a restorative urban water plan and can include green walls and roofs, stormwater biofilters (also called raingardens and bioretentions), tree pits, wetlands and other bio filtration and retention systems. They are composed of two main components: plants and media. Professor Ana Deletic, UNSW Pro Vice-Chancellor (Research) and director of SACSC has recently developed clear and simple adoption guidelines for practitioners and has improved the applicability of bio-filtration systems by adapting media and plants to local environmental conditions.

This immediate and conscious connection between research and implementation makes SACSC an attractive funding proposition and they have leveraged this financial capital into cultural capital as their reputation grows and they are increasingly sought after as a hub of expertise on the research and implementation of green technologies.

Currently Dr Zhang is heading a two-year project on the development of Biofiltration Technology (raingardens, living walls) for Stormwater Management in Jiangsu, China, supported bilaterally by Australian and Chinese government bodies. This research is timely for Sydney as well, as the 2030 Vision of the City of Sydney is to reduce stormwater pollutants by 50%, part of the 2011 City's Raingarden Policy. As of 2015, 140 Sydney street scaping projects had included raingardens. It has almost doubled since then and is expected to keep growing exponentially. Integrating raingardens into capital works reduces cost and disruption and this is a key interest to SACSC and Dr Zhang.

Raingarden efficiency and analysis is at the heart of his research. Stormwater has been wasted in the past. Gathering it and filtering it of pollutants provides a community with two resources. Nutrients filtered out become a good source of food for plants, either within the bio-filtration system itself or to local plantings. The purified water can be either redirected to infiltrate local soils or it can be used as water for irrigation or other urban necessities. Even if the water does eventually become run-off it will be purified and will cause less damage to the environments through which it travels.

Independent studies on landscape amenities values have been carried out on small raingardens at 41 Sydney intersections, involving 4000 properties. Within 50 metres properties became 6% more valuable, within 100 metres 4% more valuable. This translated to an average increase in property value at any given intersection of $1.5 million. If raingardens can be made attractive to developers and profitable in nature, then the expansion and development of this system, this way of thinking, has endless possibilities.

During this 2-year project Kefeng will be tailoring Australian biofiltration technologies to Chinese conditions. Using a variety of media to suit local ecologies, these raingardens can vary in size from a single tree pit, to the 4.5 square metre systems being piloted in Jiangsu Province, to huge 200 square metre systems that will be developed in the future. WRC is hoping to support this expansion by developing more green technology laboratory testing facilities.

The Sino-Australian Centre on Sponge City is about a globalised approach to environmental problems. It is about the sharing and flow of information. It is about discussion and co-operation. It is about hope.

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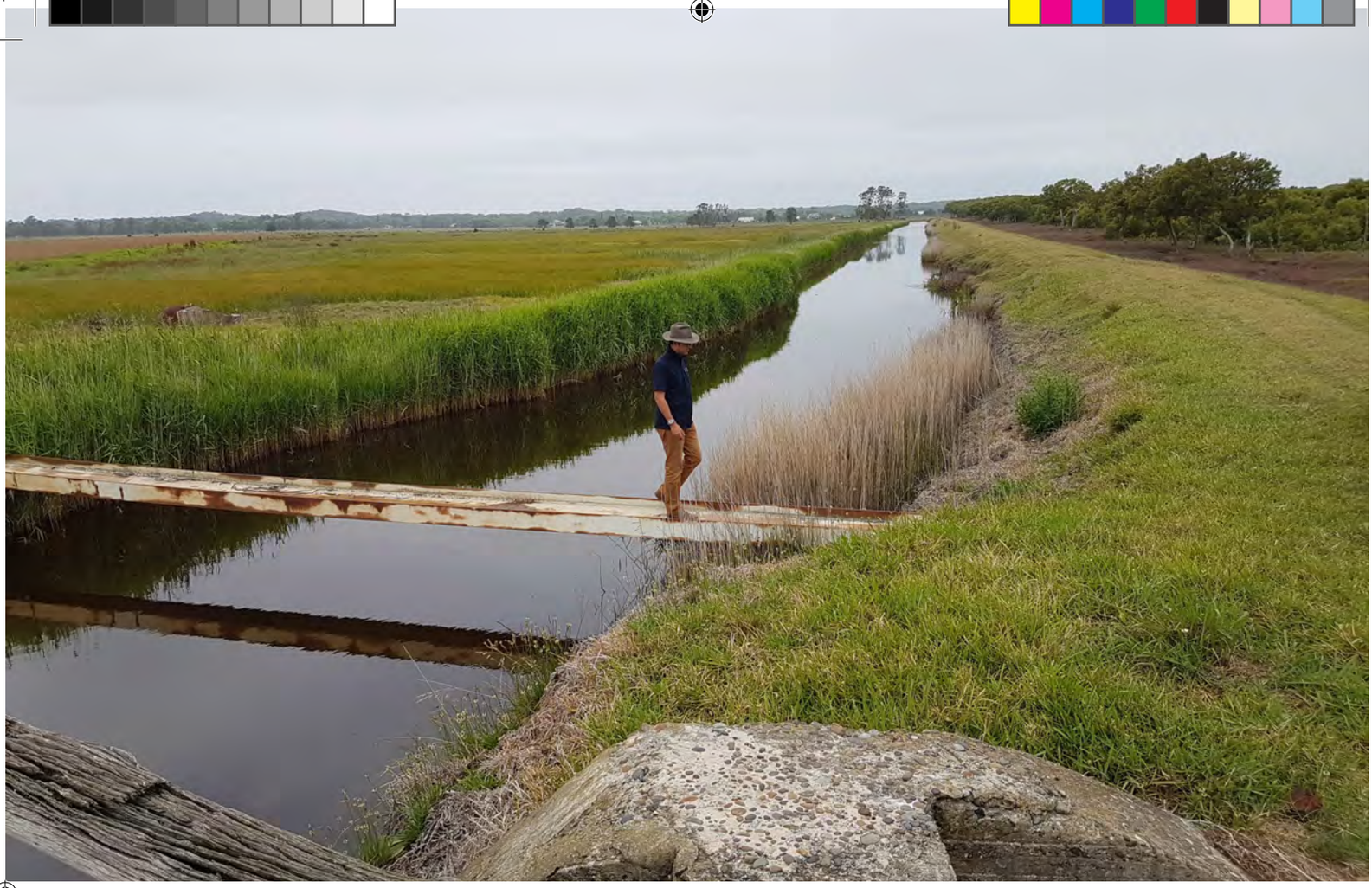

RESTORATIVE ENGINEERING AND

THE NEW ECO ENGINEER

CIVIL ENGINEERING has traditionally been about the built environment, the human made infrastructure of roads, buildings, bridges, cities, water & waste systems – all the skills, knowledge and materials that have enabled the growth of our contemporary civilisation. The 'unbuilt' environment – Nature – has been seen for long decades as either bountiful resource or unwilling victim to the march of the hard hatted army.

But perhaps true innovation is to be found in the reconciliation of these traditional antagonists. There is a new generation of engineers, ones who have grown up in a culture of heightened environmental awareness, who are beginning a new great work - of restoration. Instead of always 'moving forward', they ask, can we enact a kind of return, a return to the genius of natural systems, to heal our ailing planet?

Associate Professor William Glamore of the UNSW Water Research Laboratory is one of these new engineers. "What if, "he asks, "engineers sought linkages with ecologists to recreate nature? What if we sought to rebuild the environment?"

At its core, this is still engineering, even though it is about going back to what went before it: natural systems. It is a movement away from what humankind wants to what our whole world needs. This new eco-engineering is still focused on problem solving and project building. The innovation lies in understanding natural systems so intrinsically that we can reconstruct them biomimetically. We learn from nature instead of building atop it. We recognise and reconstruct the organising forces, understanding the layers of interrelationship between structural, behavioural and functional elements.

Professor Glamore hopes we could, in this way, avoid catastrophe. Too often today, catastrophe happens and we try to play catch up or patch up. This is especially true of localised, repetitive environmental disasters that often go unnoticed. Across

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SOLVING THE WICKED PROBLEMS: A/Prof William Glamore and team at the successfully restored Big Swamp floodplains, Taree, NSW

Australia, all around the world, every single hour of every single day, these small catastrophes happen. They are often less-than-sexy and do not provide click-worthy media content. Fish kills are such events. They are ubiquitous, avoidable and indicators of a much greater environmental imbalance.

According to the NSW Department of Primary Industries 'fish kills' are "any sudden and unexpected mass mortality of wild or cultured fish". Professor Glamore recently wrote that "fish kills are currently being reported in our estuaries across NSW. Following the recent rains, acidic runoff is discharging into our coastal rivers and wetlands. This insidious problem is killing fish, polluting waterways and acidifying our estuaries. While we know it happens every day, the magnitude of the event is always worse following big rainfall."

Fish kills reveal an imbalance. Estuaries are important; they function as the kidneys of a river and are indicators of the health of entire catchments. Estuaries in NSW are sick and the fish kills indicate this in a particularly visible and overt way. And we know why this is happening: the acidification of estuaries because of poor land use planning.

As he points out: "As with many wicked problems, no single group is responsible for creating these environmental problems and, hence, no single group is responsible for fixing them. Indeed, all levels of government were involved in creating the acid problem, but existing programs lack a prioritised or coordinated approach that can match the magnitude of the problem."

It is in precisely these kinds of contexts that a return to nature is required. But nature is astoundingly complex and endangered ecological communities require peculiarly complex solutions. They need to exist in a fine balance, influenced by numerous factors including topography, geology and hydrology. Restoring this balance, to foster the genesis of an endangered ecological community, is a multi-disciplinary challenge, but one that has been successfully accomplished in projects led by Glamore such as the WRL sponsored Tomago Wetland Restoration Project.

This project employed the very latest engineering methods and technology, including automated gates that respond to water pressure and adaptive management processes that can alter a project according to the information provided by cutting edge data collection. These approaches avoid the expensive and, at times, ineffective hit and miss methods of the past. The project won awards and recognition for the engineering team including the 2013 National Trust of Australia's Award for Conservation, a 2014 Engineers Australia Excellence Award, and the 2015 NSW Green Globe Award.

This grand environmental mission of restorative engineering requires respectful collaboration between academics, industry, landholders and governments to foster a holistic multi-disciplinary approach. Environmental engineers need to exercise not just their drive but their success, their power and their capital to communicate the desperate environmental need that supersedes the profit motive, not just to colleagues and sympathisers within their field but to other stakeholders and to a wider community.

> "Wetlands provide an important service to humans in **reducing flood** impacts."

No longer can Australians be complacent about our surfeit of natural beauty. Over the past 200 years we have transformed our rivers, floodplains and wetlands using the ungentle methods of draglines, dozers and dynamite. We have decreased fish and bird habitats, endangered ecosystems and severely impacted natural water quality processes. Environmental awareness has grown since the mid twentieth century, but we need more awareness and discussion about restorative engineering.

Glamore points to some signs of hope. Three pieces of new legislation in NSW are converging to promote a restoration industry: the Marine Estate Management Act (2014) and Regulation (2017); the Coastal Management Act (2016) and the Biodiversity Conservation Act (2016). A commercial restoration industry is developing – supported by evidence-based policies, planning efficiencies (DAs), triple bottom line accounting - driven in part by the need for sustainable fisheries production, and further supported by shifting community paradigms.

"Wetlands provide an important service to humans in reducing flood impacts, cushioning the influence of coastal tsunamis, filtering pollutants and helping communities during severe droughts, " says Glamore. "Recent research suggests that wetlands will be even more important in reducing disaster risks under increased sea levels and storms due to climate change. For our endangered and polluted estuaries and wetlands we have shown, through research and successful projects, that our landscape can be restored and that large-scale restoration is the best solution."

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AN OPEN INVITATION

The Centre for Transformational Environmental Technology is UNSW's first research base outside of Australia and will be a hub for the large-scale translation of UNSW environmental research into industrial application in China.

THE CENTRE for Transformational Environmental Technology is a huge opportunity for UNSW researchers and Australian industry," says Scientia Professor David Waite on UNSW's most recent venture.

"We are actively looking for researchers and companies with expertise in environmental technologies who want to explore the vast array of opportunities in China."

CTET, as the new centre is known, is UNSW's first research base outside of Australia and will act as a conduit for two-way information and opportunity exchange between UNSW researchers and their collaborators in China.

"The Centre is a strategic alliance with the largest high-tech zone on environmental protection in China and will showcase UNSW's environmental research credentials," says Dr Yuan Wang, Head of the Torch Precinct at UNSW.

"Specifically, CTET will provide access to local environmental problems (including wastewater and contaminated soil), which is critical when applying technologies developed in the lab to practice. It will also provide access to local industries, not only in Yixing where the Centre is located, but also in the Yangtze River Economic Belt, and across China. Importantly, the Centre will open up a stream of new funding opportunities to researchers and industry in both China and Australia," she continues.

Waite, who is the Centre's inaugural Director says the focus is firmly on fast-tracking the commercialisation of environmental technology, but there will also be a myriad of opportunities for UNSW undergraduate and postgraduate students, as well as postdocs looking for industrial experience and internships.

Professor Brian Boyle is the Deputy Vice-Chancellor, Enterprise and provides strategic leadership on all aspects of the University's enterprise and innovation agenda. He says CTET is a place where UNSW researchers will be able to connect with other experts in their field and deliver not only outstanding research but also real impact on a global scale. "Our vision for the centre is that it becomes a hub for the large-scale translation of UNSW environmental research into industries across China," he says.

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Opposite:UNSW CTET research base in China – artists impression

Dr Yuan Wang, Head, UNSW Torch Innovation Precinct, with Scientia Professor David Waite, Director of the Centre for Transformational Environmental Technology

As Wang mentioned, CTET is located in the largest high-tech zone on environmental protection in China in the Yixing Environmental Science and Technology Park, about 30 minutes by high-speed train from Nanjing and/or Hangzhou. The park covers 212 square kilometres and is home to over 100 companies from more than 20 countries and regions, all of which are exclusively focused on environmental technologies. It is part of the Chinese Torch Program that was established by the Chinese Ministry of Science and Technology about 25 years ago. The Torch Program is arguably the most successful entrepreneurial program in the world having spawned over 150 high tech zones across China.

"The Torch Program was conceived as a way of bringing like-minded industries together to undertake R&D in theme areas such as energy and environment, materials and medicine," explains Waite. "In 2016, the first Torch Precinct outside of China was established at UNSW to promote collaboration between the two countries. Not long after, our team was approached by the Torch Precinct in Yixing asking if we'd like to partner on this new Centre."

Waite says they jumped at the chance. "We have a relatively weak manufacturing base in Australia which limits the funding our researchers can access for applied R&D. Our exposure to the Chinese environmental technology industry, through the Centre, will be a huge boost for UNSW researchers in this respect."

It was clear from the start that the CTET team would need to have a permanent presence in the Yixing Torch Precinct, so they custom-designed and built the Centre which officially opened in January 2018. "Now, our focus is on promoting the Centre, generating interest among researchers at UNSW and forging partnerships in China," continues Waite.

"We have developed a framework for involvement and invited our researchers to develop a 'Capability Statement' to articulate their key research strengths. These Statements together with intensive networking will be used to develop opportunities and projects and seek funding," he says.

Wang is excited about being able to use CTET as a successful model to generate interest among UNSW alumni and existing industry partners. "We invite our alumni to find out more and come to work with our researchers. We are also happy to use our connections at the Centre to link them to Chinese industries with the aim of developing technologies that benefit the communities of both countries."

"Indeed," continues Boyle. "The success of UNSW's Torch Precinct (which has already secured over $70 million of contracts) already owes a significant debt to our alumni in China, who, as business leaders, have supported the program through their pro-active engagement with our researchers. As UNSW continues to broaden its innovation footprint in China, our alumni are crucial for its success."

> "We are actively looking for researchers and companies with expertise in environmental technologies who want to explore the vast array of opportunities."

Waite says the types of Australian organisation they are hoping to partner with ranges from small startups, who are looking to develop a single technology, through to government enterprises. "I recently visited the Beijing Waterworks Group. It's a huge operation, and they have much to learn from organisations like Sydney Water and Melbourne Water. There's a very real opportunity to transfer knowledge from Australia to China with regard to issues such as ageing infrastructure and in applying innovations in water treatment technology," he says.

"As a country whose manufacturing base developed very fast, China has a number of pressing environmental concerns. There's a clear will to manage and control them and an increasing emphasis by the Chinese government to make sure companies adhere to the environmental policies and regulations in place," Waite continues.

Because of this willingness and because of the sheer size of the market, Wang is ambitious in what she believes CTET can achieve. "I want to see UNSW labelled technologies everywhere in China in the next 5 to 10 years," she says.

Her ambition is shared by Boyle who sees CTET as just the beginning. "UNSW's Torch strategic research priorities comprise materials, health and energy as well as environment, and I would like to see all four research areas represented across China with similar centres in the very near future," he says.

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CONSTRUCTION FUTURES

How can the digital and adaptable revolution help build a sustainable future for the construction industry?

THE CONSTRUCTION industry is responsible for 18% of global greenhouse gas emissions, and is one of the biggest consumers of planetary materials. In Australia our large construction industry (in 2016 the industry accounted for 7.64% of GDP) is struggling to deal with an ever-increasing number of constraints, affecting costs and performance. There are some good reasons for this: secure safety requirements, rigorous environmental legislation and regulated wages are just three of a raft of contributing factors. We can be proud of these laws and would not want to see them weakened. But a widespread industry view is that Australia is an expensive place to deliver infrastructure.

So what are the solutions? How can we improve industry productivity while extending real benefits to society? If sustainability is truly important, what does it actually mean and how can it be achieved while improving construction productivity? How can we reduce inefficiency and waste? How can we adopt new technologies without losing sight of relationships and people?

The widely quoted Brundtland Report tells us that sustainable construction is: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” CVEN Professor, David Carmichael, believes sustainable infrastructure is based on the three pillars of economic, social and environmental considerations. In the past, economic considerations have dominated and, in some areas, continue to do so, but the balance is improving and environmental concerns, especially, are having an increased importance.

One of the great challenges for the future of the Australian construction industry is how to align productivity and sustainability as complementary concepts and ambitions. How do we make genuine environmental and social statements rather than just window dressing?

Off-site manufacturing is one solution that can help change

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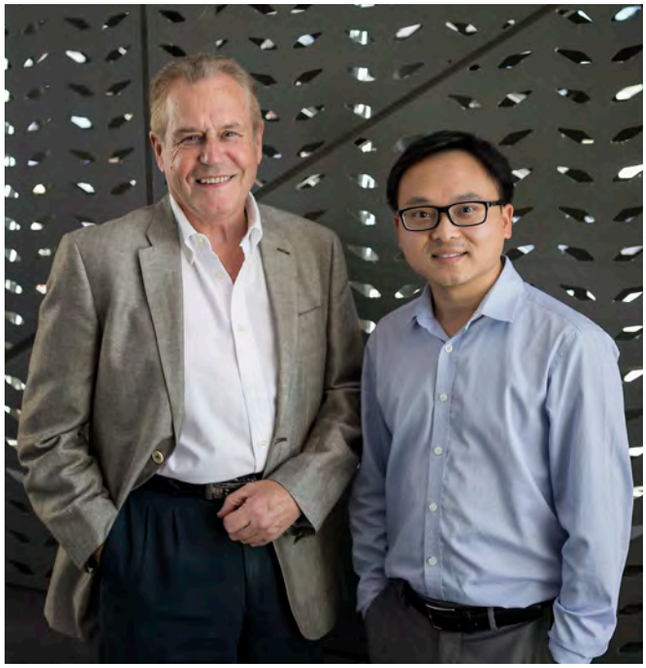

CVEN Construction Innovators: Prof David Carmichael and Dr Johnson Shen

construction. Modular building components, created in controlled workshop conditions, can reduce building costs while also reducing in-situ problems such as noise, pollution and traffic disruption. These components can be made safely, reducing the everyday dangers of construction work, while simultaneously increasing control over price, quality and timing without sacrificing creativity, individuality or design flexibility.

Some believe this is the future of construction. Innovative financiers across the globe are supporting this business model. Recently the New York Times reported about the astoundingly rapid growth of Katerra which "over just three years, has grown from a start-up with an unusual approach to the construction industry into a company with $1.3 billion in bookings." In Australia, companies such as Strongbuild are promoting sustainable offsite manufacture of hybrid timber structures.

CVEN Associate Professor Hamid Vali Pour is working in partnership with industry to research these new composites and develop the expertise that will drive this business forward. CVEN introduced, in 2017, a new fourth year course: Sustainable Timber Engineering. With direct industry input from CVEN alumnus Lisa Thom, this course has stimulated interest among students who can see the benefits of building with timber. As Professor Vali Pour says "Timber is the only truly sustainable construction material because it can sequester carbon during its service life. No other construction material will do that."

In a streamlined construction cycle, manufacturing sites are integrated with work sites through digital solutions. Buildings are becoming data gathering devices with in-built smart sensors, robotics are becoming more and more common for jobsite applications and developments in artificial intelligence (AI) make 'robots' more and more 'thoughtful'. Every onsite worker can be positioned with geospatial technologies and can be connected to every other worker. The Internet of Things (IoT) makes every device with an on/off button connected into a grand web of data.

> "How do we align productivity and sustainability as complementary concepts and ambitions?"

These digital technologies are a trend or maybe even a revolution. Dr Johnson Shen, from CVEN, believes that these innovations are a great driver for efficiency and sustainability. "Maybe construction has been lagging behind other industries in productivity but it is these digital innovations that will solve this problem."

Building Information Modelling (BIM) is a 'hot topic'. It is the process through which all data, for the whole life of an asset, is managed to provide detailed information and visualisation. It often involves 3D digital modelling that was not possible before the introduction of laser scanning (Lidar). Now Lidar has been linked with un-manned aerial vehicles (UAVs) to create a new horizon that slashes surveying time and removes humans from dangerous surveying tasks. It also helps ameliorate the shortage of registered surveyors, who can now spend their time and use their expertise analysing and interpreting data instead of gathering it.

With all these changes in technology and materials, construction needs to look at the bigger picture of how these innovations create real benefit. How can the service life of the built environment be increased, thereby reducing obsolescence and the need for demolition in the future? Sometimes engineers need to speak up and make some noise in a world driven by profit.

Professor Carmichael believes that to ensure a more sustainable construction future, the industry must adopt built-in adaptability. "With ingenuity we can inject adaptability into houses, apartment blocks, factories, offices, roads, seawalls, bridges ….. Adaptability may incur an extra initial cost and while this might be a barrier, it is a sustainability necessity. The added social and environmental benefits increase whole value, and how engineers negotiate this is a skill which needs to be taught at the undergraduate level."

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SMALL PARTNERSHIP BRINGS

HUGE SUCCESS

FOUR YEARS ago, Dr Johnson Shen had a casual conversation with a UNSW alumnus. This little chat blossomed into a research and industry practice project that is helping to revolutionise the construction industry in Australia.

Construction productivity is about cost, time, sustainability and safety. Some of the main challenges in construction surveying are: producing end-of-month volumetric measurements for project management, the extremely narrow timeframe for conducting site surveying, hazardous working environments and the dire shortage of skilled surveyors.

Dr Johnson Shen has partnered with local surveying firm Linke & Linke Surveys to develop Remotely Piloted Aircraft System (RPAS) using spinning Light Detection and Ranging (LiDAR) technology that delivers fast, accurate, real time 3D maps of targeted areas. As Director of Linke & Linke, James Linke notes, "Engineering is moving towards real-time reporting. Information that's two days or two weeks old is not as valuable anymore." Weighing just twelve kilograms, the small RPAS can travel for up to thirty minutes above any terrain, gathering data at millions of points per second and intensifying accuracy with every subsequent sweep. Cost savings are enormous and can be in the region of three thousand per cent when compared with one surveyor gathering the same amount of data.

While the "super drone" is not a cure-all or magic panacea – there will always be some construction or land surveying tasks which require higher fidelity techniques and methodologies – it does meet an extraordinary amount of construction and surveying challenges. It reduces cost and time enormously. It reduces the risks a surveyor might face in the field or onsite. It allows surveyors to meet deadlines whilst maintaining quality and accuracy. It fills a gap in an industry in need of more surveyors.

But perhaps more than anything it propels surveying and construction practices forward into a future with unlimited applications and possibilities. As Dr Shen says: "Drone technology is quite generic so it can be useful in many industries. For instance, it can be used on farms, assessing bio mass." It can be used to assess natural disasters. It can help predict bushfire likelihood by generating heat maps of bushlands.

This is a state-of-the-art technological development and Dr Shen and his Linke & Linke partners are at the forefront despite the company being an SME enterprise which has received only relatively small amounts of funding. It is an amazing achievement of collaboration and planning.

Dr Johnson Shen believes that 'hard' technological developments start with the 'soft' issue of relationship, mutual respect and shared understanding. "Industry engagement can start small, we build the relationship and the trust while we refine the scope of collaboration and customise our research to make the knowledge applicable. That is the beauty of industry and academic collaboration: universities bring an ever-developing body of expertise while industry puts it into practice."

The mutual benefits of such collaborations have not always been recognised by the construction industry in Australia. Academics need to get the message out with constant and broadening forums of communication. Johnson believes listening is the most important part.

Dr Johnson Shen is an up and coming force in technology for engineering. His research interests include automation, robotics, RPAS and hybrid variations for longer endurance, Artificial Intelligence (AI), Internet of Things (IoT), virtual reality, mixed reality, remotely piloted ground vehicles to assist in indoor mapping… the list goes on.

As he notes, universities can provide industry with cutting edge research equipment and expertise. Our people are knowledgeable and committed to engendering new ideas that can solve industry problems. With technology like the "super drone", productivity can increase exponentially.

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SLEEKER LIGHTER QUICKER

THE NEW MATERIALS REVOLUTIONISING CONSTRUCTION

SEE ANY city building site and see also parked cement trucks churning, taking up space, making noise, slowing traffic, increasing frustration. Now imagine a building site where customised, lightweight materials are delivered and easily stored, ready to use. Off-site modular manufacture is regarded by some experts as the future of construction and it is materials like cross-laminated timber (CLT) and steel-timber composites (STC) that are making that future possible.

Over the last few years CVEN Associate Professor Hamid Vali Pour has been investigating the possibilities of engineered STC wood products. "Transforming wood into an engineered wood product (EWP) reduces the dimensional instability of natural wood. EWP is less vulnerable to environmental conditions and changes like temperature and moisture. It moves less and experiences less shrinkage. Through engineering processes, we can remove the traditional defects of wood, making it more homogenous and predictable."

In 2016 Hamid was awarded one of the highly competitive Australian Research Council Discovery Grants, for nearly half a million dollars, to lead Australian research into alternative construction materials. With Professor Mark Bradford, Hamid works within the Centre for Infrastructure Engineering and Safety (CIES) to help refine these construction innovations that can build smart and sustainable cities of the future.

Use of EWP has been growing in Europe since its inception in the early 1990s. The industry has also found a healthy home in New Zealand. But the Australian timber industry is very small and is scattered over the continent, increasing transport cost and our carbon footprint. So the growth rate of timber based construction here has been small and slow.

Hamid Vali Pour believes that what is needed now is a vision and a plan for the timber industry in Australia. "First, we need to plant the trees, if we wish to have a timber industry that is producing cost efficient and sustainable product. Currently we import most of our EWP and even though the price is dropping significantly it is still too expensive to be attractive on a wide scale. We also need an expanding and skilled workforce."

Currently, buildings consist of reinforced concrete or steel-concrete composites, cast in situ. Cement is poured into formwork and propping is then required for at least a week. This is a wait of at least 10 days between storeys. Building with steel-timber composites means there is no waiting and upward construction can be seamlessly ongoing.

Alongside no wait is less weight. STC density is only 20% of concrete density. This reduces cranage and injury risk. STC increases efficiency of moving, lifting and placing panels. Hybrid construction becomes realistic: building atop older structures diminishing the social disruption of demolition, reducing waste and increasing construction adaptability.

Hamid knows this is where CVEN can be an industry leader in research and teaching. While there is much expertise in steel and concrete technologies in the Go8 group of Australia's leading universities, there are less than 5 timber construction researchers. But the School's recently introduced undergraduate unit CVEN 4309 Sustainable Timber Engineering is an indicator of coming change. The course is attracting large cohorts of enthusiastic students as well as interest and input from industry – all evidence of a coming regeneration of timber based engineering.

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21ST CENTURY MATERIALS

REDUCING THE CARBON EMISSIONS OF CONCRETE

A research project led by Associate Professor Arnaud Castel aims at transforming the concrete industry by implementing a new low carbon concrete technology.

CONCRETE IS the second most consumed material in the world after water, used most widely in the construction industry. The materials required for concrete - sand, gravel & water are often locally available and are relatively inexpensive. Cement is the glue that binds these aggregates together to form concrete – a relatively small amount of cement (about 14%) and Reinforcing steel (about 2-4%) are required for production of reinforced concrete.

Clinker is the primary component of cement, a dark grey nodular material made by heating ground limestone and clay at a temperature of about 1400 °C - 1500 °C. The nodules are ground up to a fine powder to produce cement, with a small amount of gypsum added to control the setting properties. Carbon emissions from the manufacture of clinker are second only to that of emissions from fossil fuels, and clinker is responsible for a significant proportion of Australia's total greenhouse gas emissions.

In order to reduce the environmental impact of the concrete industry, Supplementary Cementitious Materials (SCMs) such as fly ash and Ground Granulated Blast-Furnace Slag (GGBFS) have been intensively used to partially replace clinker in concrete. Currently, fly ash, a widely available by-product from coal fired power stations, is the most common SCM used in Australia.

However, to address the effects of climate change, Australia has also opted to transition from fossil fuels to renewables. The shift away from coal burning to renewable energy is expected to lead to a drastic reduction in local fly ash production. The importation of millions of tonnes of fly ash every year could put the financial sustainability of the Australian concrete industry at risk. There is an urgent need, therefore, to develop an alternative SCM available locally in suitable quantities to replace fly ash in the future. Calcined clay is a potential alternative SCM and large quantities of these clays are available in Australia. The UNSW research project led by A/Professor Arnaud Castel aims at investigating the viability of this new low carbon concrete technology.

There is some sense of urgency about the project. To preserve the sustainable performance of the entire construction industry, this new concrete technology must be ready and adopted by the industry before Australia runs out of fly ash. Castel's project will investigate the reactivity of calcined clay as a SCM in Australia. In collaboration with Dr Rackel San Nicolas at the University of Melbourne and Dr Taehwan Kim (UNSW Sydney), clays across Australia are being collected, characterised and calcined with the aim of identifying calcined clays suitable for concrete applications.

In UNSW laboratories, traditional characterisation techniques are used including Environmental Scanning Electron Microscopy (ESEM), X-Ray Diffraction (XRD) with quantitative Rietveld analysis, Fourier Transform Infrared spectroscopy (FTIR) with Attenuated Total Reflectance (ATR) attachment, thermogravimetric analysis including TGA as well as DSC, Inductively Coupled Plasma (ICP-OES) and 29Si and 27Al solid state Nuclear Magnetic Resonance spectroscopy (NMR). In addition, Automated Scanning Electron Microscopy (ASEM) combined with Data Mining Technique will allow the characterisation of the chemical and physical properties of individual calcined clay particles.

These Australian calcined clays will be used to develop Lime-

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stone Calcined Clay cement (LC3). LC3 is composed of 50% clinker, 35% calcined clay, 15 % limestone and 5% gypsum, potentially reducing the carbon footprint of cement by about 50%.

Performance-based specification of innovative construction materials is critically dependent on the ability to apply realistic and meaningful test methods. Beyond mechanical properties, the durability performance and time-dependent behaviour of Australian LC3 concretes will be assessed by Castel and his research team. The question of durability is of prime importance and is one of the main barriers to widespread adoption of new materials by the industry. Another critical aspect of reinforced concrete design is serviceability. Indeed, the control of both concrete cracking and structural member deflection is crucial. Restraint to early-age shrinkage of concrete is arguably the most common cause of unsightly cracking in concrete structures and the repair of such cracks results in high annual costs to the construction industry.

Ultimately Castel hopes to develop a new generation of performance-based standards to design durable and sustainable concrete structures. This will come in the form of a performance based handbook that will be published through Standards Australia to assist engineers and end-users in specifying and using low carbon concrete with greater confidence and less risk.

In 2018 in recognition of his expertise and leadership in the field, Associate Professor Castel has been appointed Chair of a new international Technical Committee(TC) convened by the global body, the International Union of Laboratories and Experts in Construction Materials, Systems and Structures (RILEM).

RILEM's TC will address key questions related to the rate and mechanisms of chloride transport in alkali-activated binders and concretes, with a view toward drafting recommendations for the appropriate selection and application of testing methods. The TC will bring together the world's leading research laboratories and practitioners in this area to ensure that decisions in the design, drafting and use of specifications, and future standards, can be built from this sound scientific basis.

The establishment of the RILEM Technical Committee is a significant milestone in the global cause of low carbon concrete. Castel's work within the UNSW Cooperative Research Centre (CRC) for Low-Carbon Living and his research project 'Performance based criteria for concretes: Creating pathways for low carbon concrete manufacture with existing standards' with colleagues Professor Stephen Foster (UNSW - CVEN) and Professor Jay Sanchayan of Swinburne University, has laid the foundations for such global knowledge and sharing.

Head of School Professor Stephen Foster says that Arnaud's leadership of the new technical committee 'is an important legacy of the CRC project and demonstrates the impact of our UNSW research, and the respect in which it is held, internationally.'

PROFESSOR STEPHEN FOSTER
SETTING THE STANDARDS

PROFESSOR STEPHEN FOSTER has a longstanding passion for bringing new and advanced materials technologies to the engineering of structures. His particular research interests are in the use of high and ultra-high performance concretes, fibre-reinforced concretes and geopolymer concretes, as well as in the capacity of carbon fibre technologies for strengthening and repair of structures and structural systems.

Foster is active in his professional community nationally and globally, serving on several Australian Standards committees, and is currently Deputy Chair of the Technical Council, International Federation for Structural Concrete (fib).

In January 2014, the draft Australian Standard for the design of concrete bridges was released. It was the first Standard in Australia, and one of the first in the world, to include comprehensive design procedures for steel fibre reinforced concrete (SFRC). Rules allow conventional, strain softening SFRC, but exclude the use of strain hardening ultra-high performance fibre reinforced concrete UHPFRC because of insufficient research on core aspects of the materials when conventionally reinforced.

One of Professor Foster's most recently awarded Australia Research Council Discovery Projects (DP170104618) aims to fill that gap. By investigating the shear-tension interaction performance of UHPFRC, his study, working with University of Toronto colleague Professor Frank Vecchio, expects to provide the vital data that engineers and Standards bodies need to adopt UHPFRC.

Foster has always been focused on optimisation and design, using materials as efficiently as possible to develop efficient and safe structures. Other government and industry funded research involves modelling for climate change: looking at the behaviour of structures under extreme load states, whether fire, earthquake, or significant wind (e.g. hurricane / storm loading events), because, as he says, "that's where our future challenges lie."

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PEOPLE-CENTRIC ENGINEERING

SUSTAINABLE, RESILIENT AND CULTURALLY APPROPRIATE ENGINEERING

Humanitarian engineering is experiencing a period of unprecedented global growth. With increasingly complex challenges threatening vulnerable and marginalised communities around the world, academics, researchers and students from UNSW are part of the push to grow this vital 'people-centric' engineering philosophy.

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ENGINEERS ARE increasingly questioning what the profession means to them. It has always been viewed as a noble calling, a chance to enrich people's lives, but far from this utopian ideal, many technological advancements have increased inequity across the world, enriching some, often at the expense of others, and leading educators are now questioning both the process and objectives behind engineering education.

Humanitarian engineering is a specialisation that has emerged as a response to this unfulfilled desire to increase the quality of life for all humanity and according to Dr Fiona Johnson, the specialisation is fast gaining traction. She points to the establishment of the Humanitarian Engineering Education Network of Australasia (HEENA) as a prime example.

"With HEENA, we've suddenly got a critical mass of programs and courses in universities across Australasia, and a community of educators who are passionate about working together to make sure we are meeting the dual needs of students and the vulnerable communities they'll be working for in the future," says Johnson, who is a Senior Lecturer in the School of Civil and Environmental Engineering.

Dr Robert Care, Professor of Practice at the School, says humanitarian engineering is such a unique way to view a project or problem, it has yet to be slotted neatly into the "professional circumstance", as designated by Engineers Australia. It doesn't easily fit, because it is not an engineering discipline per se, crossing many if not all disciplines. It is more a 'people-centric' engineering philosophy where the focus is to improve the lives of people in disadvantaged or marginalised communities by viewing any technological solution through the deep context of the situation.

This context is essential explains Dr Hanna Grzybowska, Senior Research Associate at the Research Centre for Integrated Transport Innovation. "The biggest existing challenge humanitarian engineers face, and also the challenge which will be very important into the future, is cultivating an ability to understand the context of the cultural background and problem before weighing in with a solution," she says.

> "**There's no one-size-fits-all solu**tion, and we need **to be open-mind**ed and respectful when it comes to working alongside other cultures."

"Some engineers like to think that cutting-edge, robust and intelligent technological solutions will solve any problem, but that's not true. Humanitarian engineers must be very creative. There's no one-size-fits-all solution, and we need to be open-minded and respectful when it comes to working alongside other cultures to ensure we design sustainable, resilient and appropriate solutions."

Johnson, alongside multidisciplinary colleagues across the Faculty, is involved in coordinating the teaching of humanitarian engineering and developing the discipline as a whole within UNSW. She explains that the University's strategic focus on having a positive global impact and social engagement dovetails perfectly with their advances in humanitarian engineering research and teaching.

"UNSW Engineering is particularly strong in water and energy research but there is other research based around humanitarian engineering, for example the work that Dr Grzybowska is doing in humanitarian logistics," says Johnson, who explains that the teaching they have developed draws strongly on the University's research strengths.

The new courses developed so far include a third-year course called Fundamentals of Humanitarian Engineering, that will be taught from the end of July 2018, and a fourth-year course called Humanitarian Engineering Project which is already underway, and from which Johnson and Care have recently returned from Nepal.

"The humanitarian project we are working on in Nepal is

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Professor of Practice Robert Care, and Dr Fiona Johnson (back row, second and third left) with students and colleagues on site in Nepal in 2018

> "With increasingly complex global challenges facing humanity, it is very satisfying to be **part of this field** of engineering and using my skills in such a positive way."

exploring the feasibility of producing biochar which can be made locally and either used to improve the health of the soil, or further processed into charcoal briquettes for heating or cooking," says Johnson, who explains that the eight UNSW students were joined in Nepal by students and researchers from Arizona State University (as part of a PLuS Alliance collaboration) and one student from Tribuhavan University in Kathmandu.

"The exciting part of this project is that the starting product for the charcoal process are the noxious weeds mikania and lantana that are threatening to smother the ecosystems of nearby Chitwan National Park, which provide important habitat for rhinoceros, elephants and the Bengal tiger," continues Johnson.

Care has 45 years' experience working as a consulting engineer in both the private and government sectors and was involved with RedR Australia (Registered Engineers for Disaster Relief) for almost five years. His role on the trip was to provide students with contacts and advice and help them troubleshoot things that will never appear in any textbooks.

"What I can do is introduce them to industry experts, help shed light on how to handle certain situations in the field and how you recover from things going wrong. Unforeseen challenges arise in all projects and I want to help equip students to successfully navigate their way through," he continues.

This groundswell of interest from researchers and academics at UNSW is also shared by students who, Johnson explains, have led the way in some respects. "Student-led chapters of Engineering World Health and Engineers Without Borders have had a longstanding presence on campus and new groups like Enactus and Impact Engineers are joining them every year," she says.

"With increasingly complex global challenges facing humanity, it is very satisfying to be part of this field of engineering and using my skills in such a positive way."

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HUMANITARIAN ENGINEERING IN ACTION

THE LOGISTICS OF HUNGER

"IT ALL starts with hunger," says Dr Hanna Grzybowska, who has spent the last few years working on a complex humanitarian logistical challenge as part of a team from the Research Centre for Integrated Transport Innovation (rCITI).

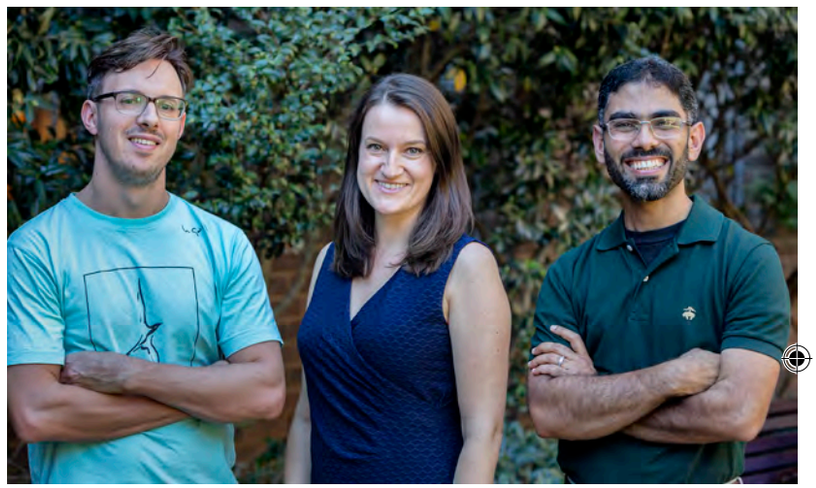
"Over 10% of the 7.3 billion people in the world suffer from hunger and the problem is not just in developing countries," she continues. "Despite Australia being a great food producing country (capable of feeding around double the current population), not everyone in Australia is fortunate enough to have a secure food situation."

In fact it is estimated that 3.4 million Australians suffer from low food security. Vulnerable groups include the aged, single or low income families, the unemployed, refugees, homeless, and people suffering from mental illness. One of the biggest ironies of a developed country like Australia is that so much food is sent to landfill – food from restaurants and supermarkets that could be used to help those in need.

This is the problem that food rescue and delivery charity OzHarvest has been working on since its establishment in 2004, namely: how do you get this food to the point where it can be consumed by those who need it in the smartest and most efficient way?

Grzybowska explains the aim of the rCITI/ OzHarvest project (which was funded by an Australian Research Council Linkage grant) was to develop a multi-objective dynamic vehicle routing algorithm that would help OzHarvest pick up and deliver the largest amount of food, to the most appropriate location, with minimal wastage, in the most timely, equitable and cost-effective manner.

With so many variables to consider it was a complex challenge for the rCITI team led by A/Prof Vinayak Dixit, with colleagues Dr Taha Hossein Rashidi, Dr David Rey and Divya Jayakumar Nair. "We needed to consider routing, the short shelf life of the food, fairness and equity in distribution, and the fact that new pickup requests arrive randomly," says Grzybowska.



Dr Hanna Grzybowska with two of her rCITI research colleagues, Dr David Rey and Dr Taha Hossein Rashidi. Left: Divya Jayakumar Nair

Their multi-objective model aimed to combine fairness in allocation and cost-effective routing without imposing restrictions on donor and welfare agencies. The team's final route update approach was computationally efficient and provided a lower route cost, a minimum wastage of perishable products and a reasonable fairness in allocation.

The result was an algorithm that can be used to not just support decision making at OzHarvest but is flexible enough to be adapted for use by organisations facing similar challenges anywhere in the world. "There is a lot of scope for the algorithm to help address a variety of global humanitarian logistical challenges which is very exciting," Grzybowska says.

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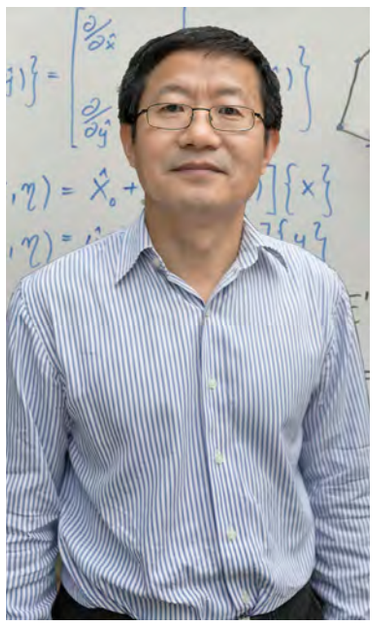
CREATING VIRTUAL CITIES

FOR ENGINEERING APPLICATIONS

SAY YOU'RE a city planner and are deciding how to zone an area for development. Or perhaps you're a transport planner and need to know the impact of a potential new tunnel on the buildings above. Or maybe you're a civil engineer and need accurate information about the impact a hurricane or earthquake will have on the building you're designing.

In any of these situations, can you imagine how useful a complete and up-to-the-minute virtual picture of your city would be? And not just for visualisation purposes, this virtual city also includes all the numerical analysis needed for engineering design.

For Professor Chongming Song, Deputy Director of the Centre for Infrastructure Engineering and Safety, this is not just a nice idea, this is the mission he has set himself and the possibility his research has opened up.



Professor Chongmin Song, Deputy Director, Centre for Infrastructure Engineering and Safety

"My vision is to provide the underpinning computational structural analysis needed to build a fully integrated virtual reality model of a city that includes all the physical and functional data," he explains.

"This means it will include the structural information of all the buildings in the city as well as all the technical information from the ground below, such as the properties of the soil and rock."

Song likens the potential impact of the virtual city to the impact of Google Maps. "Before Google Maps, if I wanted to go somewhere I needed a hard copy map and it might take a few minutes to work out the best route. Now, you can simply plug in point A and point B on your smartphone and it creates an instantaneous real-time, virtual, responsive route for you to follow," he says.

"You've probably experienced how this has saved time and made your own life easier, but for industries like transportation, the cost savings run into millions of dollars in improved routing and fuel economies. With the virtual city, I am imagining similar time and cost savings for a wide variety of industries and government agencies."

Virtual reality is increasingly being used in applications including entertainment, personnel training, architecture, design integration and construction to name a few and Song says it is so popular because it is visual and instructive. "You can see colour, layout and geometry etc, which is great, but current virtual reality methods all have a gap: they are not particularly useful for engineering design. You might have the geometry of a building, for example, but you're unable to dimension the columns and floors. That is where my technology comes in."

Although the virtual city Song has developed is just a proof-of-concept model at this stage he says he has already designed the technology needed to create it. If he can successfully apply it then everything required for analysis in the future would become automatic.

"Once we have a virtual analysis model we will be able to start doing things like inserting and taking away buildings and tunnels in a fully automated manner. That's what really differentiates this – it's incredibly practical and you will no longer need to create that physical model of the work you're planning to do."

Song explains that applications for this technology include structural analysis, building information modelling, sustainability assessment and life-cycle maintenance but, really, the only limit is the imagination and he believes there are multiple as yet unforeseen advantages to it.

"You can regard this virtual city like the virtual route I was

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talking about in Google Maps. If we can give industry the data, they will work out an amazing range of things to do with it," he says.

"It's difficult to predict which people might benefit from a new technology but I think the list would include civil engineering firms, government agencies and city planners. Looking to the distant future, I think it could also be applied in other disciplines of engineering such as biomedical engineering or mining."

> "What fascinates me most at the moment is the potential of virtual engineering to improve the safety of structures while also saving time and money."

Song says the virtual city is a passion project that has developed organically in the wake of much of his research into computational mechanics (i.e. using computers to simulate the behaviour of anything to do with mechanics, including structural engineering, mechanical engineering, biomedical engineering and other areas). But he says it has been made particularly possible by his creation of a novel numerical method called the scaled boundary finite element method.

"Many years of research has gradually led me to a realisation that the concept of the virtual city might work and now I'm very driven to achieving it," he continues. "What fascinates me most at the moment is the potential of virtual engineering to improve the safety of structures while also saving time and money."

Song's research has attracted considerable acclaim. Since 2009, he has led seven Australian Research Council Discovery Projects and been involved in or led three Linkage Projects with an accumulated research budget of over $4.8M. He explains that a large part of this interest is because his work has demonstrable real-world applications. "We have collaborators all over the world, and many people are already using the methods we've developed," he says.

Song says that, ultimately, the tool he is thinking of is a big-picture future-thinking asset that he wants to help provide for the benefit of generations to come, but he is under no illusions as to the amount of collaboration required. "This will require a huge amount of data and cooperation but building that momentum is my next area of focus. I am now working hard to establish partnerships with government and industry to ensure virtual engineering becomes a reality."

Professor Chongmin Song is actively seeking partners to explore the potential of virtual cities. If you are interested in finding out more please contact him: c.song@unsw.edu.au

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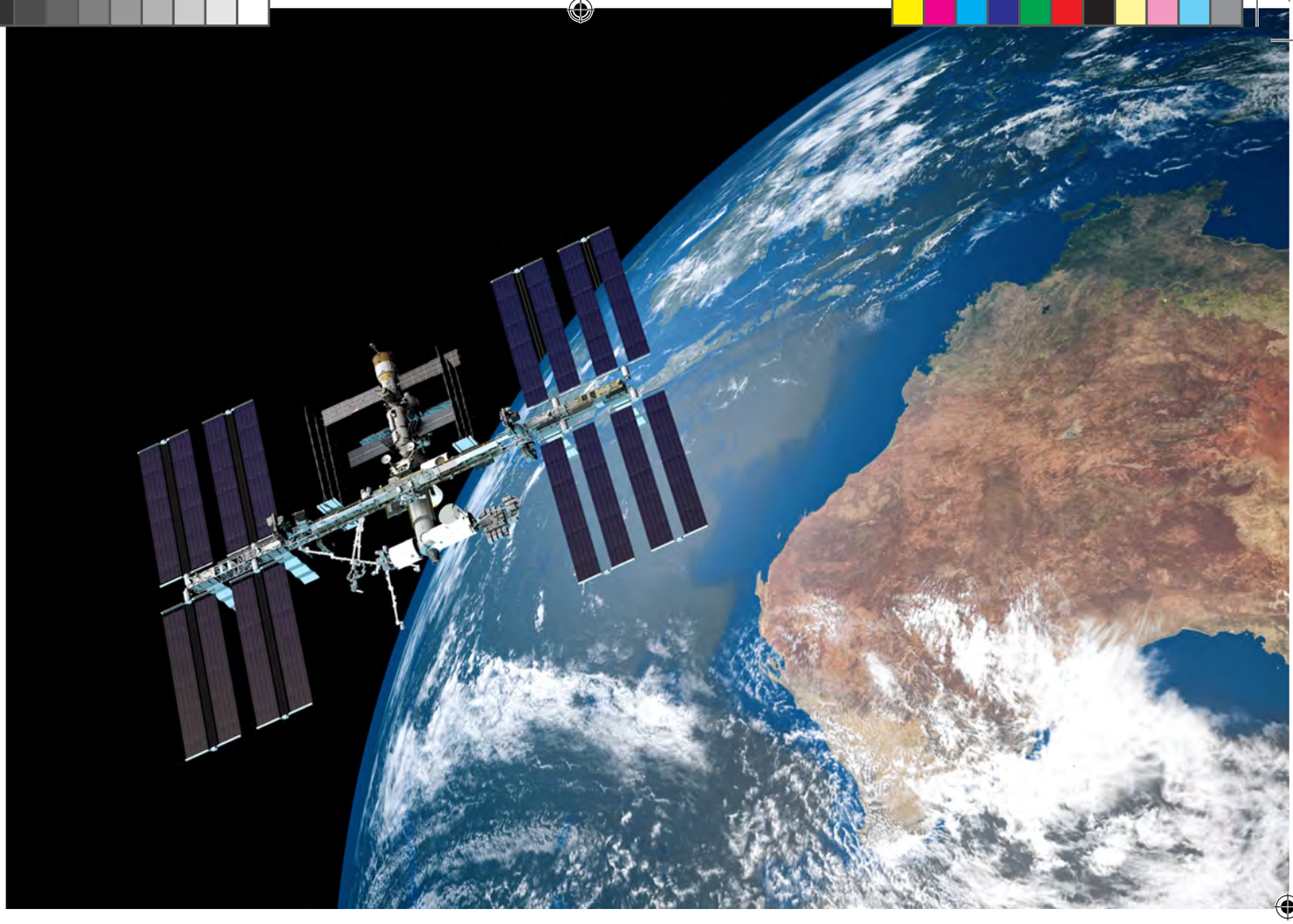

GEOSPATIAL REVOLUTIONS

THE GEOSPATIAL REVOLUTION: CHALLENGING AND CHANGING OUR MINDS

SINCE THE 1990s digital technologies have been revolutionising engineering practices, and perhaps nowhere more so than in geospatial engineering, where new and developing technologies such as GPS, satellite imagery, laser mapping and advanced computing systems are all assisting surveyors and geospatial engineers to create complex layers of interconnected geographic information.

CVEN Emeritus Professor Chris Rizos believes there is a geospatial revolution happening in positioning, mapping and remote sensing. Geography, geometry and cartography are being altered and so is our own analogue sense of space. These far reaching developments are challenging our minds and our very way of being: just as railroads did when, during the industrial revolution, they opened up our horizons and changed our sense of time.

If a map is a compressed form of data, then it is the earliest form of geospatial technology. First revolutionised by photography it is now being transformed by laser scanners that allow us to see through what used to be opaque. These scanners have given 'sight' to remotely piloted aircraft (RPAs) that can cover vast areas of land in bite sized amounts of time. Jobs that could have taken months in the past can be completed in days. Difficult surveying tasks which used to involve survey-

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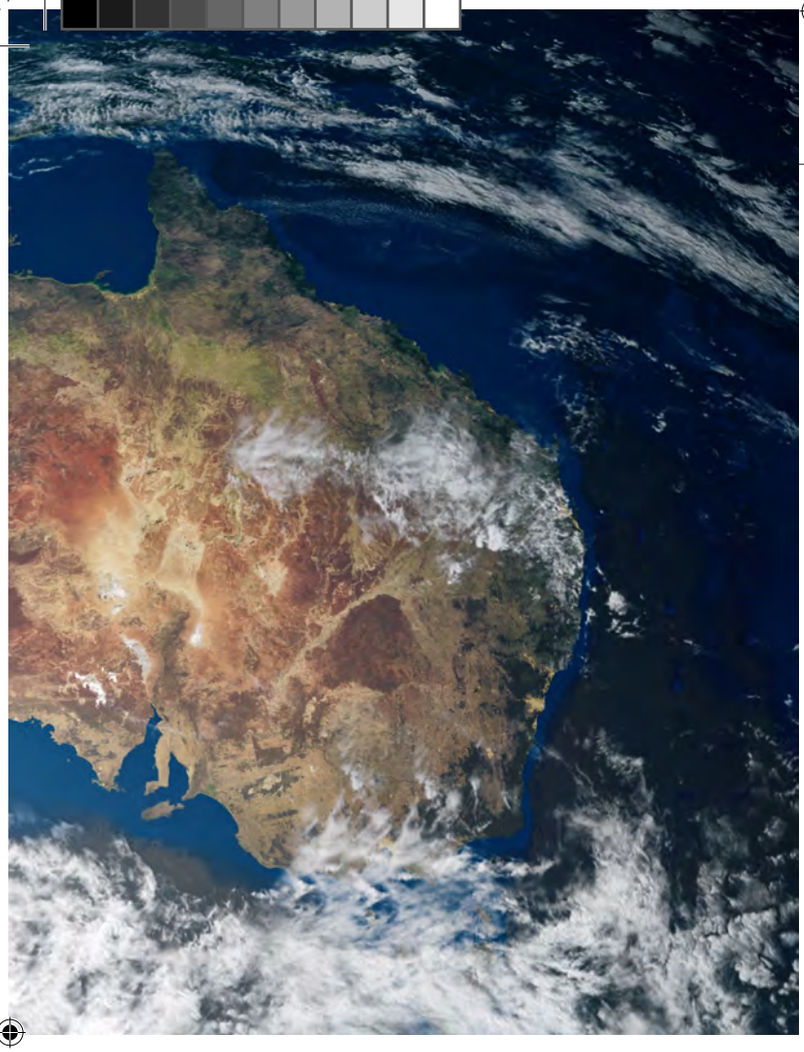

Prof Chris Rizos 'going from analogue to digital is having huge impacts'

ors climbing and clambering over precarious structures can now be completed by RPAs.

The mobility of laser scanners in Lidar technology has produced higher density mapping with billions of points in space, capturing up to millions of points per second and providing extraordinary levels of accuracy and density. Autonomous, real-time 3D mapping is a new and developing field of interest with implications for the more trivial events like road traffic to the profound destructions of natural disasters.

> "New tools do not change the fundamental principles of surveying."

Professor Rizos describes how maps, as geospatial data, have become mobile, malleable, alive and responsive. "Now maps can be drawn on devices "on-the-fly" as we need them," he says, " they can pan and zoom. We can filter information or add layers, such as superimposing socioeconomic data onto geographic detail. We can insert imaginary information like a future building or road onto the current landscape. We can add dynamic data like traffic flow on roads. We can change perspectives in an instant. We can drape imagery onto the "wire-frame" models of buildings." The list goes on.

Australia is embracing geospatial technology with gusto, resulting in a raft of home grown innovations. Global Positioning System (GPS) has been under development and refinement since the 1980s and has had a revolutionary impact on the geospatial community. It is a low-cost, easy to use, accurate, global tool for determining the coordinates of anything static or moving, on or above the earth's surface, from dekametre to sub-cm accuracy. Without GPS all images and scans would just be "pretty pictures", not geospatial information. But…. GPS does not work indoors.

Now an Australian company has developed a new technology called Locata to provide coverage where GPS fails to do so. Locata utilises a network of small, ground-based transmitters that blanket a chosen area with strong radio-positioning signals. Technologies such as Locata can revolutionise safety conditions in underground and interior workplaces such as mines and building sites as accurate positioning helps to ensure the safety of workers in an emergency.

Safety has always been a primary concern in engineering and these new technologies can create safer, healthier work environments. Automation on building sites means robots can do the heavy lifting and this is proving productive and protective in countries with ageing populations like Japan and Australia. In the future, we can look forward to more refined and complex human-robot collaborations.

Despite our analogous predisposition, we humans have swiftly become enthusiastic about and accustomed to digital realities, expecting the transfer of information to be speedy, on devices that are becoming smaller, sleeker, more efficient and cheaper.

But there is some resistance to the huge influx of digital technologies. CVEN's Dr Johnson Shen, an expert in construction innovation, puts this down to a range of factors. There is conservativism inherent in any established field that

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creates a wariness of the untried and untested. New technologies can be expensive and risky and sectors of industry are hesitant to invest. Then there are some who believe we are losing sight of fundamental knowledge amidst the furor of a revolution.

> "Australia is embracing geospatial technology with gusto, with a raft of homegrown innovations."

Recently developed geospatial technology, such as GPS, digital cameras and Lidar, are widely available and are so much easier to use than surveying equipment of the past. More and more "non-geospatially-trained" people are using the equipment without foundational instruction. This has the potential to create geo-databases with coordinates that have errors. Imagine putting up a building in the wrong place or an automated tractor running through a fence or internal walls incorrectly located during a Building Information Modelling (BIM) process? While these technologies have the potential to improve safety standards, there is also a potential for harm if used without sound knowledge.

While he believes in fully embracing innovation, CVEN Surveying and Geodesy lecturer Dr Craig Roberts is asking some necessary, pertinent and cautionary questions to those that gather and use geo-spatial data. Do those collecting geospatial data know which datum they are using? Are they equipped to recognise errors and account for them? Do they know, as surveyors do, the difference between 'ground' and 'grid'? As grid flattens the curved surface of the earth can they include scale factors?

Below: Dr Craig Roberts

After geospatial data is collected how is it understood and analysed? It is time consuming digesting and processing data and point clouds can have so much detail. So how are we to select data to create a model? On which criteria do we base selection? Where are we to find the expertise to reconcile data from many sources? How can engineering clients understand the relationship between accuracy and cost, between technology type and project type?

Once geospatial data is processed where is it to be stored? How much will this cost? Are there multiple sets of the same data? What are the impediments to sharing data? Is commercial confidentiality causing costly replication? For users of data, do they know where it has come from and how reliable that source is or shall we all just trust Google? What about ambiguous or redundant data? Who will decipher it?

These questions raise more questions about how to train students in a rapidly evolving discipline. How can geo-spatial engineering and surveying students be prepared to deal with the technological advances whilst maintaining foundational knowledges?

As Craig Roberts notes "New tools do not change the fundamental principles of surveying." But perhaps these advances may change surveying practices. Chris Rizos can see a new future emerging. "Now, because it is so easy to "make maps", surveyors are moving towards becoming spatial data managers. As Geospatial Surveyors, they are also becoming geo-IT specialists."

As the work life of a geospatial engineer is changing in very particular ways, Professor Rizos also notes that this digital revolution is changing all our lives in a very broad and abstract manner.

"Going from 'analogue' to 'digital' is having huge impacts across a wide spectrum, from merely converting paper records to images or numbers, to truly unlocking the potential for new services, new capabilities, new insights, and ultimately a new way of interacting with the physical or digital world."

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CLEANING UP THE PAST

THE LEGACY OF PFAS

JUST HOW big a problem we face in Australia regarding the proliferation of per- and poly-fluoroalkyl substances (PFAS) and perfluorooctanoic acid (PFOA) in our water supplies remains to be seen. But with contaminated sites being increasingly identified across our nation, and across the globe, the race is on among researchers to figure out how to break down and neutralise these incredibly resistant and potentially harmful compounds.

"PFAS and PFOA are very stable chemical compounds which have been used in the manufacture of a wide range of commercial and industrial applications since the 1950s," says Associate Professor Denis O'Carroll, Director of UNSW's Water Research Centre, and an expert in engineered nanoparticles in the environment, particularly in groundwater systems. "They are effective for stain, oil and water-resistant consumer products but also appear in cleaning products, paints and firefighting foams."

O'Carroll explains that PFAS and PFOA in firefighting foams are a particular problem because they have been used extensively across the world for nearly 50 years. They work by spreading foam on the fire (which smothers the oxygen and puts out the fire) and in some repeatedly used fire training areas they appear in scarily concentrated levels. "There is a pressing need to develop clean up technologies because currently there is no way to remediate sites like this," he says.

In one well-publicised Australian incident in 2016, toxic chemicals used in firefighting foam leaked from the Williamtown RAAF Base in NSW and were subsequently found in the local water and food supplies. The Department of Defence continues to investigate other sites for contamination, and chemicals have already been detected in other areas of Queensland and Victoria.

> "The big problem is that the stability of these compounds makes them incredibly persistent in the environment. "

"The big problem is that the stability of these chemical compounds makes them incredibly persistent in the environment. They are being found in many natural sources of water and in fish, animals and humans too. In the US, for example, 97% of the population has measurable quantities of these manmade compounds in their blood," he continues.

In addition to not degrading in the environment they have been found to easily move from soil to groundwater and can also travel long distances. Some studies suggest that almost every person on Earth has these compounds in their blood which gives some indication of the scale of the problem.

O'Carroll says that although alarm bells have been ringing since the 1990s only recently has there been a monumental shift in our thinking about the health impacts and risks. There is still a lot of uncertainty and much debate around the health implications, but they have been linked to cancer and immune suppression in infants.

Currently O'Carroll has teamed up with UNSW colleagues Professors Mike Manefield, Stuart Khan and Dr Matthew Lee on an ARC research project which will specifically address the PFAS problem. "Although currently, we have way more questions than we do answers," O'Carroll says, "my hope is that our work will go some way to help accelerate the eventual solutions."

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CITIES THAT DON'T CONSUME THE EARTH

An internationally acclaimed expert in the fields of integrated sustainability and carbon footprint analysis, Associate Professor Tommy Wiedmann has a sobering message for our cities.

ASSOCIATE PROFESSOR Tommy Wiedmann is a passionate defender of this finite planet and his research revolves around the question - how do we achieve concurrent human and planetary well-being? One of the world's most widely cited academics, Tommy has recently been contributing to the international report 'Consumption-based Green House Gas Emissions of C40 Cities'. The C40 Alliance functions as a global facilitator of conversations, as a research hub and a generator of bespoke climate change solutions for modern cities.

Cities emit 70% of the world's carbon dioxide. Or so we thought. In actuality, it could be much higher than this. Carbon footprint accounting has traditionally been focused on sector-based production. The innovation of this report, and part of Tommy Wiedmann's core research mission, is the inclusion of consumption-based emissions in its account and analysis of individual cities. His team at UNSW has partnered with the University of Leeds, UK, to develop the model and calculations for the C40 report.

Interestingly, the report revealed that much of a city's footprint lies outside its boundaries. "We have done this consumption-based analysis for 79 cities around the world, including for the cities of Sydney and Melbourne. We found that about half of Sydney's and Melbourne's carbon footprint comes from outside of the city boundary."

The broadened equation of consumption based analysis: consumption = production + imports - exports, creates a truer and more alarming picture but it does allow city planners to develop inventories and strategies that can target the real problem. And seeing the true picture is vital.

"We're still going in the wrong direction on climate change," said Mark Watts, executive director of C40 Cities. Global carbon emissions have increased 60 percent since the international 1997 Kyoto agreement to reduce emissions. Using more renewable energy and mass transit won't be enough to reverse this. We have to reduce our consumption."

Tommy Wiedmann adds "All the efforts to reduce emissions from buildings and traffic are good, but they are, by far, not the only emissions we need to look at. We need to make equal efforts to reduce emissions in building materials and from food production and we need to address emissions from consumption."

Wealthy, service-based 'consumer' cities like Sydney and Melbourne are in fact outsourcers of pollution. Many cities in developing nations, who are producing obvious GHGs, are often doing so in the process of producing our consumer goods. When the emissions associated with our consumption of goods and services are included, our cities' emissions have grown substantially and, according to the C40 Report are among the highest in the world on a per person basis.

Much of the responsibility and the power, then, falls to us, the citizens. And we can act now, as communities and as individuals. Shopping consciously with ethical, environmental and sustainable local and global production in mind, and in daily practice. As Wiedmann says, "Smart and sustainable cities of the future will have to be zero carbon 'inside' and low carbon 'outside'. They will have to be regenerative, absorbing CO2 emissions from the atmosphere through green infrastructure, and making the most of reusing, repurposing and recycling goods, materials and waste."

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