NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

PUSHING

# FRONTIERS

## BUILDING GREEN, URBANISING SMARTLY

MAKING A CITY FUTURE-READY

### FORTIFIED FROM LAND TO SEA

Underground engineering and coastal protection drive sustainable growth

### TECHNOLOGY IN TRANSIT

Transport gets greener, smarter and swifter

### BUILDING INTELLIGENT INFRASTRUCTURE

High-tech innovations for smart living

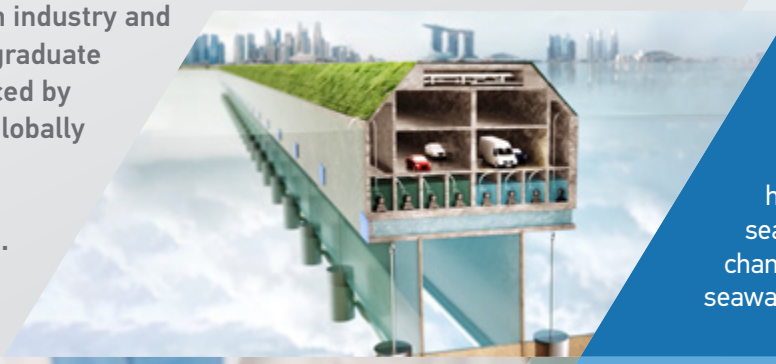
ISSUE 24
2024

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

# INNOVATIVE URBAN SOLUTIONS FOR THE WORLD

A leader in research and development for sustainable cities of the future, the Centre for Urban Solutions is housed in the School of Civil and Environmental Engineering at Nanyang Technological University, Singapore, a young and research-intensive university ranked among the world's top universities.

The centre partners with industry and trains talent at the postgraduate level to tackle issues faced by cities, as well as hosts globally competitive research programmes addressing urgent urban challenges.

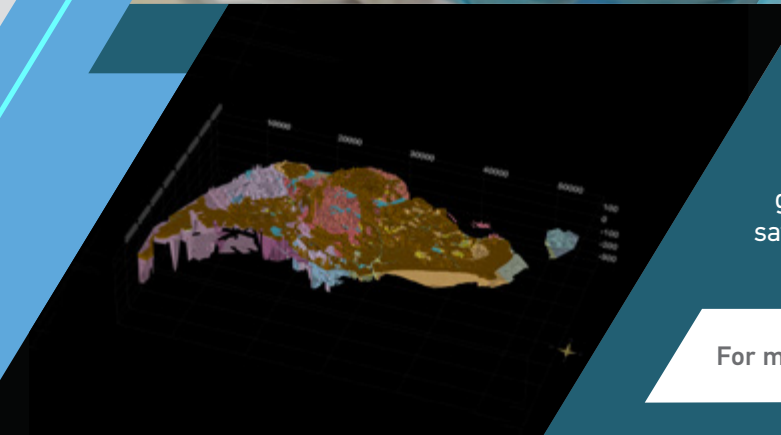


## Fighting sea-level rise

Engineers strategies to help cities adapt to rising sea levels caused by climate change, such as flexible seawalls with multiple uses.

## Making construction sustainable

Develops environmentally friendly building materials, such as eco-cement made from waste, to reduce carbon emissions and improve energy efficiency.



## Understanding the underground

Establishes systems to help city planners better understand Singapore's subsurface geology, which can make underground projects safer and more cost-effective.

For more information, visit us at https://www.ntu.edu.sg/cus




Stories in this issue can also be found at *ntu.sg/research-hub*

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# CONSTRUCTING RESILIENT CITIES

It is estimated that almost 7 in 10 people will live in urban areas by 2050. Alongside this growth in urban population, environmental issues such as climate change and pollution have emerged as some of the biggest threats to the sustainability of cities.

A leader at the forefront of technological advances, NTU builds strengths that foster the sustainable development of smart cities. From self-healing concrete to automated building mapping, innovations from a broad range of disciplines at the University are shaping a liveable tomorrow.

These and other urban solutions are highlighted in this issue of *Pushing Frontiers*.

To address space constraints faced by densely populated cities, NTU researchers are exploring the use of underground space. They are also devising multifunctional sea walls that protect coastal areas from erosion while creating new space for development.

Aviation and maritime transport are vital for transporting people and goods around the world. NTU researchers are integrating eco-friendly energy solutions into the maritime industry. With the help of artificial intelligence, they are also making air transport and shipping operations more efficient.

Other smart city applications that NTU researchers are working on include using 3D printing in construction and developing digital tools that facilitate urban planning.

In the age of automation, research from NTU is also paving the way towards better human-robot interactions and increased trust in self-driving vehicles.

I am excited to be NTU's new Vice President (Research), taking over the baton from Prof Luke Ong. I would like to thank Prof Ong for all his work and wish him every success in his new appointments as Vice President (AI and Digital Economy) and Dean of NTU's College of Computing and Data Science.

Research is now very collaborative, involving experts from different fields, initiatives and countries. NTU provides an ideal ecosystem for interdisciplinary research and partnerships. I look forward to working with researchers across every domain at the University to push the frontiers of knowledge.

*Prof Ernst Kuipers*
*Vice President (Research)*
*Nanyang Technological University*
*Singapore*

Credit: Richard Whitcombe/Shutterstock

# SEEDING THE FUTURE

**New college for next-generation innovators in artificial intelligence**

NTU has launched the College of Computing and Data Science to drive artificial intelligence (AI) research and education efforts at the University. The new college will nurture AI talent who are socially conscious, as well as accelerate interdisciplinary collaboration between computing and other disciplines.

Research platforms at the college will focus on generative AI, promote research in cyber security and digital trust, study how AI can help to address humanity's grand challenges, and develop new interdisciplinary areas of scientific inquiry using AI.

In line with NTU's commitment to lifelong learning, the college will also offer industry-relevant continuing education and training courses in areas like AI, data science and computing.

Leading these efforts to steer NTU's growth in the AI age is eminent computer scientist Prof Luke Ong, NTU's Vice President (AI and Digital Economy), who previously led the University's research enterprise.

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**Professorship for top scientific minds**

Paeonia Foundation, the philanthropic arm of Paeonia Group, has gifted NTU S$5 million (US$3.8 million) in support of the University's research and education endeavours. The fund will be used to set up the Alice Y. Hung Professorship in Science and Technology at NTU to attract and train the best and brightest minds, with a portion of the gift going towards an academic collaboration with the University of Pennsylvania (UPenn) in the United States.

Paeonia Group is a Singapore-headquartered single-family office and an international investment holding company set up by Ms Alice Yin Hung, an industrialist and entrepreneur who is a member of the NTU Board of Trustees.

The professorship will enable the appointment of international distinguished academics at NTU to promote research excellence and nurture scientific talent, especially in the area of precision instruments for analytical chemistry, which reflects Paeonia Group's business interest in scientific analytical instruments.

NTU will also work with UPenn – Ms Hung's alma mater – to support a leadership development programme for undergraduates, faculty and executives.

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**Sensitive parenting benefits children's self-development**

Parents are said to demonstrate sensitive caregiving when they notice and appropriately respond to their children's need to explore the world and feel safe in it.

This parenting style helps children feel secure in exploring their surroundings, and has a positive influence on their physical health and development in areas such as emotional regulation and higher-order thinking.

NTU researchers are now investigating interventions to promote sensitive caregiving. They are examining how these interventions impact the emotional and physical wellbeing of children, as well as the role genetic factors and biological mechanisms play.

The research is in collaboration with the National University of Singapore; the Singapore Institute for Clinical Sciences at the Agency for Science, Technology and Research (A*STAR); KK Women's and Children's Hospital in Singapore; and various international research institutions.

The five-year project is led by Assoc Prof Anne Rifkin-Graboi, Deputy Centre Director at the Science of Learning in Education Centre at the National Institute of Education in NTU, and is supported by the National Research Foundation, Singapore, and A*STAR under its Prenatal/Early Childhood Grant.

## SEMICONDUCTORS

# DESIGNING COLOUR-CHANGING SEMICONDUCTOR MATERIALS

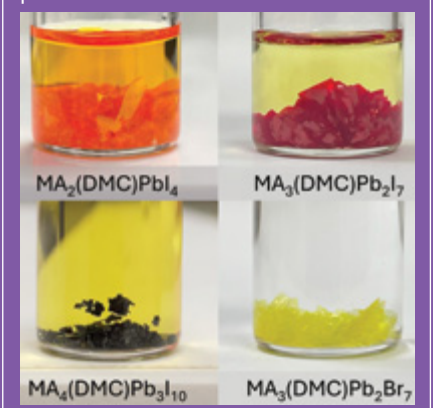
Semiconductor materials known as 2D halide perovskites can be used in devices such as solar cells and light-emitting diodes. Scientists led by Assoc Prof Nripan Mathews of NTU's School of Materials Science and Engineering have synthesised four unique types of 2D halide perovskites.

Dr Ayan Zhumekenov, a research fellow at the school and lead author of the study, used a novel approach to create the new perovskites by incorporating dimethyl carbonate – a non-toxic solvent – into methylammonium-based perovskite crystals.

By analysing the new crystal structures, the scientists discovered that the structures' band gap could be tuned by adjusting the ratio of methylammonium to dimethyl carbonate in them. The band gap, which determines the colour of the material, is the energy required for an electron to break free from its bound state and become conductive.

The ability to engineer the width of the band gap is important for the various applications of perovskites.

The new 2D halide perovskites also exhibit a dynamic "switchable" behaviour. The researchers found that one of the perovskites could switch between two coloured states, changing from orange to red when heated to 80 degrees Celsius and reverting to its original colour when cooled to room temperature.



NTU's novel perovskites. Credit: NTU.

The scientists demonstrated that the colour-changing reaction could be repeated for 25 cycles. This phenomenon of thermochromic switching opens the door to applications such as smart coatings and heat-sensitive inks that change colour at different temperatures.

The scientists hope their innovation will pave the way for technological applications of 2D halide perovskites in optoelectronics and beyond.

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*The research was published in "Solvent-templated methylammonium-based Ruddlesden-Popper perovskites with short interlayer distances" in* Journal of the American Chemical Society *(2024), DOI: 10.1021/jacs.3c12891.*

## AUTONOMOUS VEHICLES

# 'FEARFUL' SELF-DRIVING VEHICLES ARE SAFER ON THE ROAD

Autonomous vehicles powered by artificial intelligence have many advantages, but ensuring that they make safe decisions in risky scenarios remains a challenge.

Mimicking the workings of the amygdala, a part of the brain that processes emotions, NTU researchers have developed a machine learning model that can "feel" fear.

This enables autonomous vehicles to learn defensive driving behaviours and take safer actions.

Humans feel fear when faced with unpleasant events or uncertain situations and learn to avoid them. The researchers programmed fear into the model by incorporating anticipated negative stimuli and uncertainties in its decision-making process.

Their experiments found that the model had a lower collision and traffic violation rate in ambiguous road situations than other autonomous driving programmes. The model also outperformed human drivers in avoiding collision when a vehicle suddenly cut into its lane.

"By helping autonomous vehicles make the correct decisions while on the road, our model could make transportation safer," says Assoc Prof Lyu Chen of NTU's School of Mechanical and Aerospace Engineering, who co-developed the model with his team.

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*Read more in "Fear-neuro-inspired reinforcement learning for safe autonomous driving" in* IEEE Transactions on Pattern Analysis and Machine Intelligence *(2024), DOI: 10.1109/TPAMI.2023.3322426.*

RECYCLING

# MAKING PLASTIC REUSE GREENER

Electronics is one of the largest contributors to plastic waste. Plastics from electronic waste (e-waste) pose an environmental hazard if not disposed of properly as they often contain toxic chemical additives.

One such contaminant is brominated flame retardants (BFRs) that make e-waste plastics fire-proof. These compounds leach out of the plastic into the environment when e-waste plastics are discarded. Heating the plastic during recycling also releases the toxic compounds.

Now, NTU scientists led by Assoc Prof Lee Jong-Min of NTU's School of Chemistry, Chemical Engineering and Biotechnology have come up with a way to make e-waste plastic recycling safer. Using a mixture of 1-propanol and heptane, they dissolved and removed BFRs from acrylonitrile butadiene styrene – a type of plastic commonly used in the casings of keyboards and laptops.

The solvents dissolved only the BFRs, enabling the researchers to recover over 80% of the plastic after removing the BFRs. The properties of the plastic were also unchanged. The researchers hope that their method will facilitate the recovery of clean plastic and increase the recycling of e-waste plastic.

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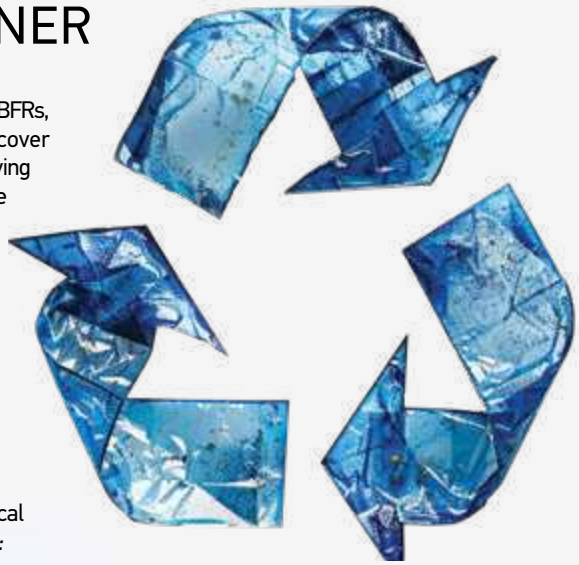
*The findings were published in "Enhanced extraction of brominated flame retardants from e-waste plastics" in* Chemical Engineering Journal *(2023), DOI: 10.1016/j.cej.2023.144126.*



CARBON DIOXIDE CAPTURE

# REDUCING CARBON EMISSIONS FROM WASTE DISPOSAL

Incinerating solid waste is an important waste management strategy that greatly reduces the amount of non-recyclable solid waste and generates energy at the same time. However, burning waste produces carbon dioxide that contributes to greenhouse gas emissions and climate change.

One method to minimise carbon dioxide emissions from incineration plants is to use calcium oxide to capture the emissions. In this process known as calcium looping, calcium oxide reacts with carbon dioxide to form calcium carbonate when heated to temperatures of around 650 degrees Celsius. The reaction is reversible, and carbon dioxide is released from the calcium carbonate at higher temperatures of about 900 degrees Celsius. The released carbon dioxide can then be purified for other purposes.

However, calcium looping is energy-intensive and expensive. To evaluate its feasibility in incineration plants, researchers led by Assoc Prof Grzegorz Lisak of NTU's School of Civil and Environmental Engineering constructed a detailed model that accounts for the different variables in calcium looping.

From their model, the scientists found that using fuels produced from recovered waste for heating was the most economical and that leveraging waste-derived calcium sources, such as incineration ash, can further reduce the overall cost of this technology. Carbon credits and taxation that incentivise negative emissions also make calcium looping more economically viable.

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*Find out more in "A techno-economic assessment of the reutilisation of municipal solid waste incineration ash for $CO_2$ capture from incineration flue gases by calcium looping", published in* Chemical Engineering Journal *(2023), DOI: 10.1016/j.cej.2023.142567.*

## LANGUAGE STUDIES

# AGE MATTERS WHEN LEARNING NEW LANGUAGES


A recent NTU-led study has shown that the ability of older individuals to learn new languages could depend on how competent they are in their first language.

Dr Kastoori Kalaivanan, a research fellow at the NTU-Cambridge Centre for Lifelong Learning and Individualised Cognition, and Assoc Prof Alice H.D. Chan from the University's School of Humanities, found that Tamil-English bilingual Singaporeans whose first language is Tamil had varying levels of Tamil and English perceptual sensitivity – the ability to distinguish between similar speech sounds that differentiate words in a language.

The ability of younger participants (aged 19 to 33) in the study to perceive Mandarin Chinese tones not native to them depended strongly on their general intelligence and, to a lesser degree, their perceptual sensitivity in Tamil. But the ability of older participants (aged 55 to 70) to distinguish Mandarin Chinese tones is solely dependent on their perceptual sensitivity in Tamil.

These findings suggest that younger and older adults may process non-native speech sounds differently, and that age-related differences should be considered when developing language learning programmes for adult learners.

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*Details of the study can be found in "Native language perceptual sensitivity predicts nonnative speech perception differently in younger and older Singaporean bilinguals", published in* Journal of Speech, Language, and Hearing Research *(2023), DOI: 10.1044/2022_JSLHR-22-00199.*

## NATURAL HAZARDS

# UNCOVERING THE SECRETS OF A DEVASTATING EARTHQUAKE

On 1 January 2024, a devastating magnitude-7.6 earthquake struck the Noto Peninsula in Japan. The earthquake caused severe shaking, a tsunami and landslides, which killed almost 300 people and damaged over 46,000 homes. It was the deadliest earthquake in Japan since the Great East Japan Earthquake in 2011.

Earthquakes are generally caused by abrupt, rapid movements of pieces of the Earth's crust along fractures known as faults. Researchers working with Assoc Prof Wei Shengji of NTU's Asian School of the Environment and Earth Observatory of Singapore showed that the Noto earthquake started unexpectedly in a zone that was thought to have limited capability of initiating a powerful earthquake.

From their analysis of satellite and seismic sensor data, the scientists discovered that the earthquake started from an unusually slow movement along a fault. The slow movement was likely due to fluids in the fault and the heterogenous composition of the faults. This type of earthquake presents a challenge for current earthquake early warning systems, which are less likely to pick up signals from the slow movement to trigger alerts for large earthquakes.

The findings contribute to an in-depth understanding of how earthquakes occur and highlight the importance of analysing multiple datasets to estimate seismic hazards. The research may also aid the development of more accurate tools for seismic and tsunami hazard assessment.

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*The discovery was reported in "Slow rupture in a fluid-rich fault zone initiated the 2024 $M_w$ 7.5 Noto earthquake" in* Science *(2024), DOI: 10.1126/science.ado5143.*

## PHOTONICS

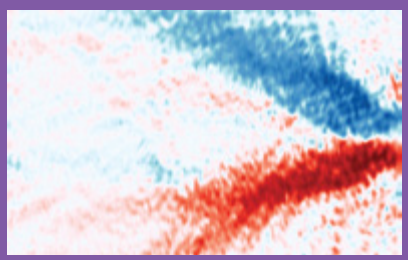
# CONTROLLING LIGHT-MATTER PARTICLES AT ROOM TEMPERATURE

Researchers have found a way to manipulate special hybrid particles called polaritons – which behave like both light and matter – at room temperature. The breakthrough enables the use of polaritons in high-speed computing and data processing.

Polaritons have a property called "spin", which is akin to a polariton spinning clockwise or anti-clockwise on its axis. How polaritons spin allow them to encode computer data. Changing how they spin and move thus modifies the data stored in polaritons.

But such changes to polaritons have only been possible at ultra-low temperatures close to the coldness of outer space, making them expensive and impractical to maintain. Now, a study co-led by Nanyang Asst Prof Su Rui from NTU's School of Physical and Mathematical Sciences (SPMS) and School of Electrical and Electronic Engineering, as well as Assoc Prof Timothy Liew from SPMS, has shown that polaritons could be manipulated at room temperature when they are created.

The particles are generated by shining a green laser on a material called caesium lead bromide with a layer of liquid crystal molecules in a microcavity structure.



An electric field applied to a microcavity structure caused polaritons with different spins to move away from one another in opposite directions. This is visualised here by a spectrometer, with red polaritons spinning in one way separated from blue polaritons spinning the other way after they moved apart. Credit: NTU.

The researchers controlled and changed the movements of the polaritons, based on how they spin, by applying an external voltage to them.

This method of manipulation allows the polaritons to store, transfer or process data at faster rates than current computing technologies because polaritons travel at the speed of light.

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*Details of the study are found in "Polariton spin Hall effect in a Rashba-Dresselhaus regime at room temperature", published in* Nature Photonics *(2024), DOI: 10.1038/s41566-023-01375-x.*

## SCIENCE COMMUNICATION

# INCREASING ACCEPTANCE OF NOVEL FOODS

Findings from a study by Prof Shirley Ho and PhD student Ou Mengxue from NTU's Wee Kim Wee School of Communication and Information could help inform science communication strategies that address misinformation on novel foods, such as genetically modified vegetables or laboratory-grown meat.

To determine if having expert knowledge influences how people evaluate information on novel foods, the study held focus group discussions with 40 participants in Singapore – a quarter of whom were novel food experts.

The study found that lay people who do not know much about novel foods and find it difficult to understand technical jargon tend to give up assessing whether the information they read about the foods is credible to save themselves time and effort. Lay people also tend to rely on superficial aspects of the information, such as whether it comes from a legitimate-looking website.

On the other hand, some novel food experts choose not to verify the credibility of the information because they lack time and want to concentrate on their research instead. When they do try to determine the accuracy of the information, they focus on the content such as whether the details appear objective or seem too good to be true, and if the information aligns with the broader scientific understanding.

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*The research was reported in "Does knowledge make a difference? Understanding how the lay public and experts assess the credibility of information on novel foods", published in* Public Understanding of Science *(2024), DOI: 10.1177/09636625231191348.*

## EDUCATION

# INSPIRING PURPOSE IN HIGH-ACHIEVING CONTEXTS

Does your school or organisation contribute to a better world? Modern-day schooling is mainly focused on the "what" and "how" of good education that centres on best practices in teaching and learning, as well as measuring how well students have learnt.

In the book *Inspiring Purpose in High-Performance Schooling*, Assoc Prof Mary Anne Heng from the National Institute of Education in NTU makes an urgent call for a new vision of education, which emphasises a deeper purpose that goes beyond celebrating achievements to pursue the "why" of education.

She points out that a personally meaningful education fosters a deep awareness of our connection to something greater than ourselves and helps us discover our larger purpose in the world.

Using Singapore as a case study, Assoc Prof Heng analysed multiple sources, including surveys, individual student interviews and insights from practising teachers and education leaders.

Her research uncovered that the discovery of purpose and meaning by students in schools was ad hoc and left to chance. It was also observed that academic stress in high-achieving education settings may lead to mental health issues among students.

But education with a larger purpose provides students with a clear direction and sustained motivation for their academic and life experiences, and helps them develop as human beings with positive goals to lead good lives together.

Assoc Prof Heng advocates that students need alternative narratives of success and suggests ways to transform education towards a larger purpose based on three core principles: being true to oneself, reaching towards aspirational goals and inspiring people to act towards a greater good.

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*The book* Inspiring Purpose in High-Performance Schooling *is published by Routledge (2024).*


The book calls for a new vision in education that helps students develop a deeper purpose that extends beyond academic achievements. Credit: Routledge.

## GENETICS

# IDENTIFYING THE RISK FACTORS OF PARKINSON'S DISEASE

Parkinson's disease can cause slowed movement, muscle stiffness and uncontrollable movements like shaking limbs in patients.

A large-scale study has found genes in human chromosomes associated with the neurodegenerative disease that are common across people of different ancestries, shedding new light on the condition and its potential treatments.

The research, co-led by Nanyang Asst Prof Foo Jia Nee from NTU's Lee Kong Chian School of Medicine, analysed the genetic data of nearly 50,000 patients with Parkinson's disease, close to 19,000 individuals with a parent who has the disease and 2.4 million people who do not have the disease.

Unlike previous studies that focused on single populations, especially European patients, the researchers looked at data across four population groups: people of African, East Asian, European and Latin American descent.

The analysis found 78 specific spots on human chromosomes that contain genetic sequences linked to Parkinson's disease. Of these, 12 locations had not been identified before.

After comparing the results with publicly available data, the researchers identified 25 potential genes in four of the novel locations that may play a role in the development of the disease. Of these genes, several are implicated in the body's immune and inflammation responses.

The researchers said that the results lay the groundwork for future efforts to identify additional genetic sequences linked to Parkinson's disease in non-European patients.

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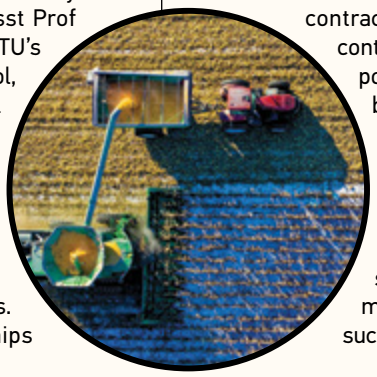
*Details of the study can be found in "Multi-ancestry genome-wide association meta-analysis of Parkinson's disease", published in* Nature Genetics *(2023), DOI: 10.1038/s41588-023-01584-8.*

## FINANCE

# A MACHINE LEARNING APPROACH TO WEATHER INSURANCE

Researchers have used machine learning to design a more cost-efficient insurance contract that could better protect farmers against weather risks arising from climate change.

The research team, co-led by Assoc Prof Zhu Wenjun and Asst Prof Zhang Jinggong from NTU's Nanyang Business School, used a type of artificial intelligence (AI) called neural networks to uncover intricate relationships between weather variables such as temperature and rainfall, and crop production losses. The complex relationships unearthed were remarkably different from those described by conventional linear models that are more straightforward.



Based on the results of their empirical case study, the researchers designed an AI-based weather index insurance contract for farmers. The contract could improve policyholders' wealth by nearly 5% with a 37% lower price compared to the current average price considered in the study. This stands to improve market demand for such products.

The findings open the way for governments to optimise initiatives to reduce the financial burden on public agencies and develop innovative measures to help the agriculture sector during a climate-related crisis.

The new insurance policy could also enhance the overall wellbeing of farmers by helping them get the most benefit from the policy and feel more secure about their financial situation, despite challenging climate conditions.

The outcomes of the research also set the stage for a paradigm shift in using AI to design financial products potentially across borders and even those in industries beyond agriculture.

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*Read about the research, "Managing weather risk with a neural network-based index insurance", published in* Management Science *(2023), DOI: 10.1287/mnsc.2023.4902.*

## GENOMICS

# THE ORIGINS OF THE WORLD'S FAVOURITE BEVERAGE

Arabica coffee is the world's most economically important coffee species. Now, researchers have traced its origins to Ethiopia hundreds of thousands of years ago.

The international team of scientists, led by NTU's Asst Prof Jarkko Salojarvi from the School of Biological Sciences, uncovered this by studying the genomic origins and breeding history of the Arabica coffee plant.

The plants analysed by the scientists included an 18th-century specimen that Swedish biologist Carl Linnaeus, the father of taxonomy, used to name the Arabica species.

From their research, the scientists postulated that Arabica stemmed from a chance event 350,000 to 610,000 years ago in Ethiopia, when two other coffee plant species naturally cross-pollinated to create the first Arabica plants in the wild.

The Arabica coffee plant. Credit: NTU.

The classic cultivated Arabica plants of today do not have resistance to the devastating coffee leaf rust – an infectious fungal disease that can destroy the plant. The study found that this resistance may have been lost when Arabica plants became widely cultivated.

However, the researchers also identified a new combination of genes transferred from a different species of disease-resistant coffee plants, which could help protect Arabica plants vulnerable to coffee leaf rust.

The highly detailed genomic sequence of the Arabica coffee mapped by the study also means that other useful traits could be improved in the future. These include the coffee's resilience under dry weather, better crop yield and more aromatic coffee beans.

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*Details of the study can be found in "The genome and population genomics of allopolyploid Coffea arabica reveal the diversification history of modern coffee cultivars", published in* Nature Genetics *(2024), DOI: 10.1038/s41588-024-01695-w.*

# BUILDING GREEN, URBANISING SMARTLY

## MAKING A CITY FUTURE-READY

Research in NTU is paving the way for sustainable and smart urban development.

The urban population is growing. About 56% of the world's population currently lives in cities, but by 2050, urban residents are expected to make up nearly 70% of the population. As cities grow, however, so too will issues related to sustainable development.

For cities to manage rapid urbanisation and stand the test of time, growing sustainably is imperative. The cities of tomorrow need to be liveable, eco-friendly and technologically equipped. To help cities become both green and smart, researchers from NTU are developing diverse solutions that tackle sustainability, urban and industry challenges.

In building sustainable cities, for instance, the environmental impact of the materials used should be minimised. NTU researchers have developed biocement from waste by-products and are exploring the use of mycelium – the network of threads that make up a fungus – in construction.

In a project supported by a national initiative to develop low-carbon energy technologies, one NTU team from the School of Civil and Environmental Engineering (CEE) turned incineration ash from Singapore's waste treatment plants into materials that capture carbon emissions. The study also looks into purifying both waste ash and captured carbon for use in construction.

"These innovations address challenges that urban cities face and contribute to their sustainability," says Prof Chu Jian, Chair of CEE and President's Chair in Civil Engineering.

A city built to be sustainable must be resilient too, particularly in the face of climate change. The interdisciplinary Climate Transformation Programme launched by NTU is addressing the impact of climate change on healthcare, biodiversity and the economy across Southeast Asia.

Prof Benjamin Horton, the programme's lead investigator and Director of NTU's Earth Observatory of Singapore, remarks: "The concern about climate change is that we will come to a point where it's too late, because we've crossed tipping points in how the Earth works that we cannot recover from."

Urban resilience is also reflected in disaster preparedness. Researchers from NTU's School of Social Sciences have designed a model for healthcare systems that helps policymakers manage risks in large-scale crises, such as the COVID-19 pandemic. The model, developed by simulating scenarios across 16 hospitals in Indonesia, can recommend the most efficient response strategy based on various factors, such as the number of disaster victims and hospital bed availability.

In planning for urban sustainability and resilience, smart technologies have become essential. One focus area for many cities is smart transport. In 2016, Singapore's Land Transport Authority and JTC Corporation partnered with NTU to establish the Centre of Excellence for Testing and Research of Autonomous Vehicles-NTU (CETRAN) to support the country's roll-out of autonomous vehicles by developing technical standards and capabilities to test the vehicles.

"We operate the CETRAN AV test centre where autonomous vehicle framework testing is performed not only by NTU, but also independent developers. Over the years, we've looked at different types of autonomous vehicles, including 12-metre-long buses, taxis, shuttles, road sweepers and mobile robots," explains Mr Niels de Boer, Senior Programme Director at CETRAN.

Autonomous vehicles are made possible with artificial intelligence (AI), which is now a key technology across sectors. But the prevalence of AI raises concerns – how trustworthy are these AI-based services and the parties providing them? In 2022, Singapore's Infocomm Media Development Authority and National Research Foundation appointed NTU to establish the Digital Trust Centre, which also houses the Singapore AI Safety Institute.

The centre leads the nation's research in trust technologies to enhance trust in the digital economy by protecting people's personal data in the digital space, establishing trusted identities in a borderless world and assuring the safe and responsible use of AI models. Such technologies also allow multiple parties to perform analytics without sharing their data and models.

# FUTURE-PROOFING A CITY

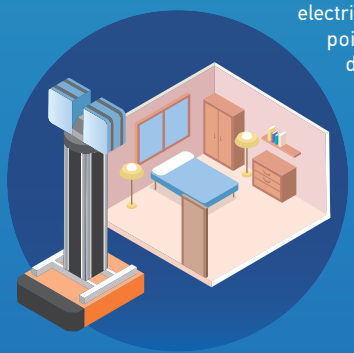
**From making construction materials greener to advancing marine technologies, NTU drives research and innovation in sustainable urban growth. Here is a glimpse into NTU's various research projects.**

## SHIP PERFORMANCE ANALYSIS

Dr Liu Shukui from NTU's School of Mechanical and Aerospace Engineering devised a way to predict the impact of sea waves on ships that can help gauge the true performance of vessels and optimise their routes to reduce greenhouse gas emissions. The method has been adopted by the International Maritime Organisation, the International Towing Tank Conference and the ISO15016 standard.

## AUTOMATED BUILDING MAPPING

Assoc Prof Cai Yiyu from NTU's School of Mechanical and Aerospace Engineering has automated the workflow of mapping a physical space, including identifying features like mechanical and electrical plumbing, to produce data points for modelling a building digitally. Leveraging various technologies, the innovation reduces data conversion time, energy and costs by 80%. NTU spinoff CHiLX.ai will be commercialising the product.





## GREENER MARINE FUEL

Dr Imran Ibrahim from the Maritime Energy and Sustainable Development Centre of Excellence in NTU found that biodiesel made from renewable feedstock can significantly lower greenhouse gas emissions in small vessels operating in ports compared to standard marine fuel. The team is now trialling biodiesel on larger vessels, such as tugboats.

## 3D-PRINTED BATHROOM

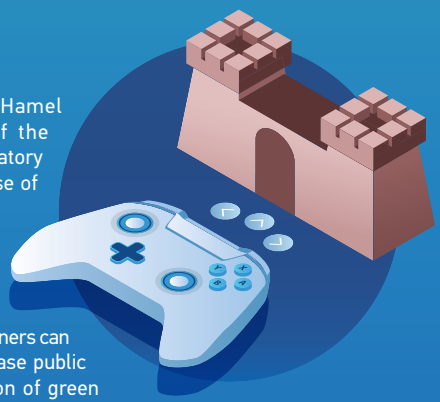
Prof Tan Ming Jen from NTU's School of Mechanical and Aerospace Engineering developed a technology that 3D-prints a prefabricated bathroom unit in half a day. This speeds up construction of such units by 30% and eliminates the risk of errors arising from manual labour. The 3D-printed units are also 30% lighter, with built-in lattices for fixtures like sewerage and electrical wiring without requiring additional piping and drilling.

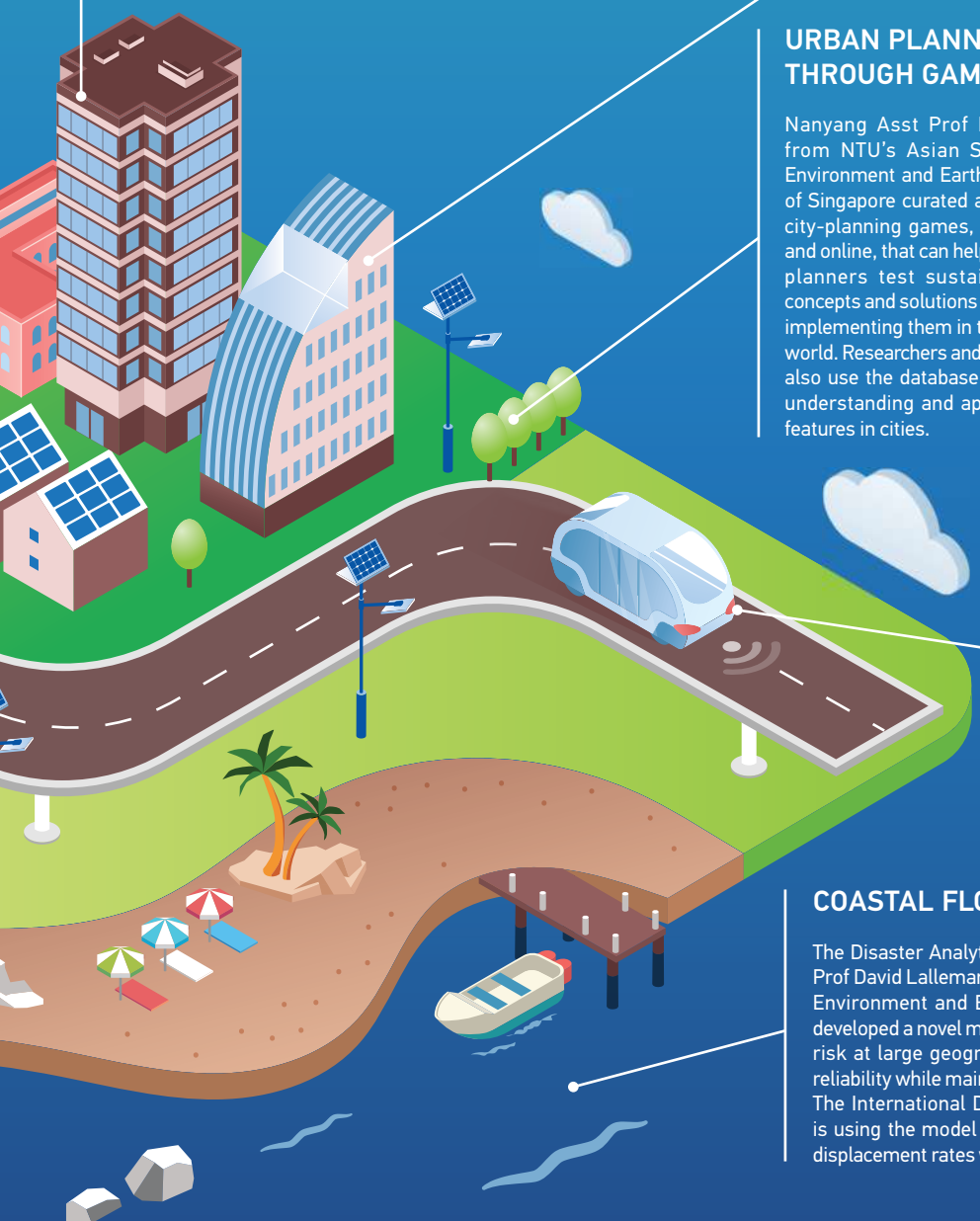
## LONG-LASTING CONCRETE STRUCTURES

Assoc Prof Yang En-Hua from NTU's School of Civil and Environmental Engineering developed a bendable metal-like concrete that is less prone to sudden breaks and can potentially enhance the safety of buildings and infrastructure while reducing their lifecycle cost and carbon footprint. He also formulated a self-healing cement additive that could strengthen the durability of concrete used in critical infrastructure.

## URBAN PLANNING THROUGH GAMES

Nanyang Asst Prof Perrine Hamel from NTU's Asian School of the Environment and Earth Observatory of Singapore curated a database of city-planning games, physical and online, that can help urban planners test sustainable concepts and solutions before implementing them in the real world. Researchers and practitioners can also use the database to increase public understanding and appreciation of green features in cities.





## VIRTUALLY TESTING SELF-DRIVING SYSTEMS

A framework developed by Mr Roshan Vijay from the Centre of Excellence for Testing and Research of Autonomous Vehicles-NTU enables autonomous vehicle systems to be simulated and tested virtually. It is a flexible, modular and open-source resource that researchers and developers can use to design safer vehicles.

## COASTAL FLOOD RISK MAPPING

The Disaster Analytics for Society Lab led by Assoc Prof David Lallemant from NTU's Asian School of the Environment and Earth Observatory of Singapore developed a novel model that can assess coastal flood risk at large geographic scales with high levels of reliability while maintaining computational efficiency. The International Displacement Monitoring Centre is using the model to project coastal flood-induced displacement rates worldwide over the next 80 years.

# FORTIFIED FROM LAND TO SEA

## UNDERGROUND ENGINEERING AND COASTAL PROTECTION DRIVE SUSTAINABLE GROWTH

**NTU researchers are strengthening critical infrastructure both below ground and by the sea with advanced technologies and innovative materials.**

Land and resource limitations are becoming more prevalent as the global population expands. This is especially true in sprawling megacities where millions live within tight geographical boundaries.

Developing underground space could be a solution to address urban land scarcity. Urban subterranean space is often underutilised and its development could uncover new social, economic and environmental possibilities that shape the cities of tomorrow. Innovations that protect coastlines from erosion, prevent low-lying areas from being submerged and create space for urban development, especially in the face of rising sea levels caused by climate change, could be part of the future of coastal cities.

In response to urban challenges, researchers from NTU's School of Civil and Environmental Engineering (CEE) are diving deep, literally, focusing on both developing space below ground and protecting coastal regions. These projects include new digital platforms to reduce costs and enhance safety in underground construction, and green building materials to stabilise shorelines and adapt to rising sea levels.

Supporting the school's endeavours is the Centre for Urban Solutions (CUS), a multidisciplinary initiative to provide leadership in research and development of innovative solutions for sustainable living and infrastructure for future cities. The centre seeks to address urban development challenges by integrating digital technologies, such as artificial intelligence (AI), into urban planning and construction.

## EYEING THE DEPTHS

One area that CUS focuses on is underground engineering. In land-scarce cities, space is being created through not just upward expansion, such as high-rise buildings,

but also downward development. This subterranean push fortifies the city for future expansion as well.

Assoc Prof Wu Wei, who heads CUS' Underground Engineering Cluster, runs cross-functional teams pioneering digital solutions to manage the unpredictable underground. "Digging up to 100 metres deep poses significant engineering challenges, such as managing costs and controlling surface settlement to prevent accidents like the ground collapsing," he explains, citing a spate of devastating sinkhole incidents that have occurred worldwide during construction projects.

His group has developed methods powered by AI to precisely map underground structures like cavities or boulders, employing machine learning to detect anomalies autonomously.

"Our machine learning algorithms sift through geological data to identify deeper and clearer anomalies compared to existing approaches. This method reduces costs, cuts the need for constant human supervision and greatly enhances the efficiency and accuracy of our underground assessments," Assoc Prof Wu notes.

CEE researcher Asst Prof Shi Chao has similarly turned to transformative digital solutions for underground and coastal engineering. His research team uses algorithms and digital twins – virtual models that simulate subsurface conditions – to optimise the construction of underground infrastructure. These virtual models accelerate real-world predictions and analyses when assessing the suitability of underground spaces for use, minimising the need for physical testing.

"We harness emerging AI technology to combine geological knowledge and site-specific data to automatically build and update digital twins," explains Asst Prof Shi, stressing the need for accurate underground modelling to reduce risks in safety and project failure.

His team has successfully applied the digital twin approach in Hong Kong, assessing conditions such as slope stability and the structural integrity of the seabed for land reclamation and tunnelling projects. In cities with limited land resources, digital twins can help mitigate the risks of building on challenging soil conditions.

"The success of our models in solving complex engineering challenges brings us closer to revolutionising civil engineering and integrating advanced technologies to improve the efficiency, safety and sustainability of our infrastructure," adds Asst Prof Shi.

## SAFEGUARDING OUR SHORES

Meanwhile, cities with low-lying coastlines face the imminent threat of rising sea levels. Singapore's latest national climate change study projects an increase of up to 1.15 metres in sea level by the end of the century, exceeding previous estimates.

Prof Chu Jian, Chair of CEE and Director of CUS, is leading the charge on two research projects under the Coastal Protection and Flood Resilience Institute Singapore to mitigate this threat: improving shoreline stability and exploring sustainable materials for coastal protection. His work could also support land reclamation projects through novel construction methods and improving soil properties to enhance the stability of reclaimed land.

One such innovation is biocement, a durable and sustainable cement alternative produced from waste by-products, embodying circular economy principles. The material could be used to build tube-like bunds along the coastline that protect beaches from strong waves and accumulate sediments like sand. In time, the bunds could help restore eroded shorelines and prevent further erosion due to rising sea levels.

"We tested biocement as a solution to prevent beach erosion at East Coast Park in a pilot project carried out with the National Parks Board, a Singapore public agency. Evaluations of the tests are underway," says Prof Chu.

Currently, about 70% of Singapore's coastline is safeguarded by coastal protection structures such as seawalls. Now, CUS researchers are working with national coastal protection agency PUB and the industry to develop alternative coastal protection structures using modular floating concrete units with impervious flexible seawalls that can adjust to changing sea levels. These structures could serve as coastal protection solutions that are multifunctional in incorporating roads and recreational spaces within or at the top of the modular units.

The work at CEE and CUS emphasises balancing engineering ingenuity with environmental sustainability. "We are taking a holistic approach to coastal protection and water management strategies. It's important to design solutions that have minimal impact on the environment, which is why we harness nature-based innovations," shares Prof Chu.

Prof Chu is optimistic about the research outcomes of CEE and CUS, which are bolstered by strategic collaborations with industry and government. "Most of our research projects are funded by government agencies or industries that address national needs directly," he says. "All the work contributes to building up a city's resilience against the changing climate."

**"Most of our research projects are funded by government agencies or industries that address national needs directly. All the work contributes to building up a city's resilience against the changing climate."**

Prof Chu Jian
*NTU's School of Civil and Environmental Engineering*

# TECHNOLOGY IN TRANSIT

## TRANSPORT GETS GREENER, SMARTER AND SWIFTER

**Scientists at NTU are making a sustainable push for air, land and sea transport.**

From commercial flights to sea freight and daily train commutes, it has become more convenient to move people and goods from one place to another. However, modern-day transport contributes to over a third of global carbon dioxide emissions. It also accounts for nearly 30% of the world's energy consumption.

To reach net zero, nations are finding ways to decarbonise transport. At NTU, various research groups are spearheading efforts to make our transport systems smarter and more sustainable.

### GREENER AT SEA

As the backbone of international trade, the maritime sector is a billion-dollar industry on a continuous growth uptick. Similarly growing is its carbon footprint: maritime greenhouse gas emissions rose by 20% in the last decade, accounting for 3% of global emissions. In countries like Singapore where maritime is crucial for the economy, decarbonisation is a priority.

"For us to achieve environmental sustainability and to reinforce Singapore's position as a leader in maritime innovation, it is essential to integrate green energy solutions into the maritime industry," shares Dr Imran Ibrahim from NTU's Maritime Energy and Sustainable Development Centre of Excellence (MESD CoE), a research centre jointly funded by the University and the Singapore Maritime Institute to develop solutions for greener ports and shipping.

As part of Singapore's efforts in maritime decarbonisation, MESD CoE is collaborating with the Maritime and Port Authority of Singapore to transition new vessels used only within the country's port to full-electric propulsion and net-zero fuels. One attractive carbon-free fuel is ammonia, which could cut shipping greenhouse gas emissions by up to 61%.

However, ammonia is toxic and needs to be handled with care. To facilitate the safe use of the fuel, Dr Liu Ming from MESD CoE is improving the industry's understanding of how ammonia spreads and disperses in the air when released, as well as proposing mitigation measures against accidental ammonia release.

Through theoretical modelling and simulations, Dr Liu's team has identified different patterns of how ammonia disperses in the air. These insights can guide the industry in choosing the right mitigation measure based on different scenarios.

Moving forward, the team has planned field experiments to validate their findings and deploy proposed mitigation technologies. "The outcomes can be directly applied to create safety features at future ammonia bunkering facilities in Singapore," states Dr Liu.

**"For us to achieve environmental sustainability and to reinforce Singapore's position as a leader in maritime innovation, it is essential to integrate green energy solutions into the maritime industry."**

Dr Imran Ibrahim
*NTU's Maritime Energy and Sustainable Development Centre of Excellence*

## SMARTER IN AIR

Aviation is one of the fastest growing contributors of greenhouse gases as aircraft burn large amounts of fossil fuel. A considerable proportion of fuel – up to 15% – is consumed during aircraft taxi-out (before take-off) and taxi-in (after landing) phases. In certain high-congestion scenarios, this figure can be higher.

Researchers at NTU's Air Traffic Management Research Institute (ATMRI) are pioneering advancements in air traffic management to reduce taxiing delays and the corresponding fuel usage.

"ATMRI's research integrates advanced technologies such as artificial intelligence (AI), machine learning and data analytics into air traffic management systems," says ATMRI's Deputy Director, Assoc Prof Sameer Alam. A collaboration between NTU and the Civil Aviation Authority of Singapore, ATMRI is notably the first institute outside Europe to participate in the Single European Sky ATM Research 3 Joint Undertaking initiative that seeks to transform Europe's air traffic management using digital technologies.

One groundbreaking innovation from ATMRI is the Intelligent Departure Metering Advisory Tool (I-MATE), an AI-driven assistant designed to enhance the departure metering process for air traffic controllers. Departure metering involves scheduling aircraft to wait at the gates rather than on runways before take-off, thereby reducing runway congestion and fuel wastage due to aircraft idling on the airside.

Traditionally, air traffic controllers manually coordinate departure timings, balancing the need to avoid taxi-out delays with the goal of optimising runway traffic. "When runway traffic forecasts are uncertain, controllers find it challenging to consider them effectively when scheduling aircraft departures," notes Dr Hasnain Ali from ATMRI.

While currently available model-based departure metering tools offer some assistance, they often oversimplify the complexities of real-world air traffic management. In contrast, I-MATE employs deep reinforcement learning, a sophisticated AI technique that allows it to learn iteratively from simulated experience and adapt its strategy to dynamic and uncertain situations.

"We have conducted validation experiments to assess the efficiency and acceptability of I-MATE in assisting air traffic controllers to manage airside traffic in a realistic simulated environment. The results revealed a significant reduction in taxiing delays (25.6%), alongside increased compliance with I-MATE recommendations. This may translate to improved efficiency, cost savings for airlines and an enhanced passenger experience," explains Dr Hasnain.

European data suggests that reducing taxiing delay by one minute could save about €62 (S$90.82) per commercial flight, including expenditure from burning fuel and reactionary delays. The decrease in fuel consumption would also result in a proportional drop in related emissions.

## SWIFTER ON LAND

Electric rail networks, such as the Mass Rapid Transit (MRT) system in Singapore, are more environmentally friendly than fossil fuel vehicles as they produce less carbon emissions. For this major transport system that ferries millions of passengers daily, preventive track maintenance is integral to ensure smooth operations.

"Current MRT track maintenance, however, relies on regular visual inspections conducted by trained personnel, who use camera-based systems designed to detect cracks, wear and faults. These methods mean that issues are only identified after they have occurred," says Prof Yang Yaowen from the University's School of Civil and Environmental Engineering (CEE).

Together with Asst Prof Fu Yuguang from CEE and Prof Gao Cong from NTU's College of Computing and Data Science, Prof Yang is piloting an AI-based smart sensing system that gives early warning of potential problems. By attaching fibre optic cables along stretches of tracks and installing small accelerometers at strategic points, vibration signals from passing trains can be captured. The vibration data is analysed in real-time by a sophisticated AI model that picks up anomalies on the tracks or the train.

Maintenance teams can then be speedily deployed to pinpointed locations. "Early detection of problems and intervention will help prevent delays and reduce the likelihood of unexpected service interruptions. For commuters, this means a more reliable and efficient MRT with fewer breakdowns," highlights Prof Yang, emphasising the importance of proactive maintenance.

# Beating air pollution and bacteria with nanoparticles

## Using silk proteins and tiny particles to make air filters

By Lam Yeng Ming and Liu Zheng

*Prof Lam Yeng Ming is the Chair of NTU's School of Materials Science and Engineering (MSE) and President's Chair in Materials Science and Engineering. Her research aims to understand and design functional nanomaterials with novel structures that have applications in sustainable energy, food production and environment remediation.*

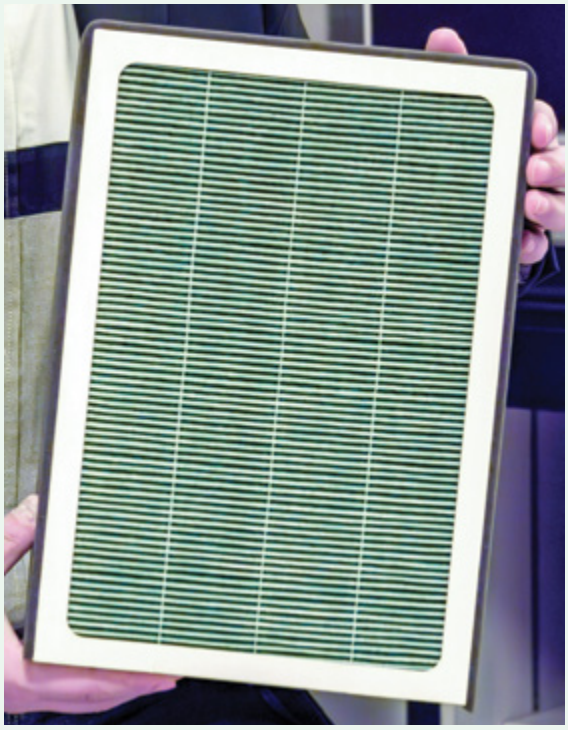
*Prof Liu Zheng, President's Chair in Materials Science and Engineering at MSE, works on the synthesis, engineering and application of ultra-thin 2D materials. His research has resulted in novel materials for high-performance electric devices, electrocatalysts and photocatalysts.*

*Details of the research presented here can be found in* Chemical Engineering Journal *(2021), DOI: 10.1016/j.cej.2021.131947; and* ACS Applied Nano Materials *(2022), DOI: 10.1021/acsanm.2c02736.*

Air pollution, particularly in cities, is harmful to human health. Polluted air contains microscopic particles called PM2.5 that can cause lung and heart diseases. Bacteria in the air can contribute to disease too.

Highly efficient air filters can alleviate these urban challenges, but many traditional filters cannot remove PM2.5 particles that are 2.5 micrometres in size – about 40 times smaller than the diameter of a strand of hair. These filters are also not able to kill airborne germs like bacteria that can be smaller than 1 micrometre.

To address these issues, we explored and combined two approaches to develop an air filter that is mechanically stronger, biodegradable and highly effective at filtering out air pollutants and eliminating bacteria.



The commercial silk fibroin protein filter with lanthanum nitrate and cuprous oxide nanoparticles, co-developed by NTU and Renmin University of China, was able to remove 99.9% of bacteria and tiny particles of different sizes in polluted air. Credit: NTU.

### ANTIBACTERIAL COPPER

Our first approach is to use nanoparticles made of copper, which has long been known to have antibacterial properties.

In fact, the ancient Greeks and Aztecs used mixtures or compounds containing copper for wound treatment. Studies have shown that some forms of copper nanoparticles are safe for human use and, in some cases, even beneficial for open wounds. Other research suggests that copper nanoparticles can destroy viruses too.

We studied nanoparticles made of a copper compound, called cuprous oxide, about 150 nanometres in diameter,

as well as smaller copper metal particles at 50 nanometres. We spray-coated them separately onto fabrics commonly used to make face masks and filters for air purification such as in ventilation systems in hospitals and aeroplanes.

The bacteria-killing ability of the coated fabrics was tested using antibiotic-resistant bacterial strains of *Klebsiella pneumoniae* and *Pseudomonas aeruginosa*, which can cause pneumonia and blood infections respectively.

Fabrics coated with cuprous oxide nanoparticles had an average bacterium killing efficiency of over 93%. For fabrics with a layer of metallic copper nanoparticles, the efficiency was more than 84%. In all instances, bacteria were eliminated within 45 seconds.

We observed that the nanoparticles produced free radicals and unstable molecules that can damage cells, and found damaged bacteria DNA. These findings suggest that cuprous oxide and metallic copper nanoparticles induced the formation of free radicals that cause oxidative damage to bacteria and kill them. Another possibility is that electrostatic forces between the bacteria and the nanoparticles stretched and disrupted the bacteria's membranes, thereby destroying them.

Further tests showed that after six days of exposure to *K. pneumoniae*, the cuprous oxide-coated fabrics had a sustained ability to kill the bacteria.

## ELECTROSTATIC ATTRACTION

Our second approach to improving air filtration involves mixing electrostatic nanoparticles with silk fibroin, a protein extracted from silkworm cocoons.

The nanoparticles are made from lanthanum nitrate and 300 times smaller than the width of a strand of hair. Lanthanum nitrate is used to speed up chemical reactions in industrial processes. It also produces an electrostatic effect that can better attract and trap tiny particles when squeezed or pressed. We added these nanoparticles to silk proteins to create nanosized fibres for air filtration.

Testing the strength of this nanoparticle-silk protein filter, we found that its breaking strain – how much the material can stretch before it breaks – was 2.1 times higher than that of a filter made purely from silk proteins.

In terms of performance, our filter reduced the concentration of PM2.5 particles simulated using cigarette smoke by 92%. It also filtered out 98% of *Escherichia coli* and *Staphylococcus aureus*, bacteria that cause gut and skin infections respectively.

To further improve our filter, we added nanosized graphitic carbon nitride that is known to kill bacteria under sunlight. The filter neutralised 99% of *E. coli* trapped in it after exposure to ultraviolet light, which is found in sunlight, for 120 minutes. The mechanical strength of this filter was also comparable to our original filter without graphitic carbon nitride.

Both versions of our silk protein filter are biodegradable, breaking down after being buried in the soil for nine days. While the nanosized lanthanum nitrate and graphitic carbon nitride did not easily degrade, the quantities used were low, and they are considered eco-friendly and not harmful to living things.

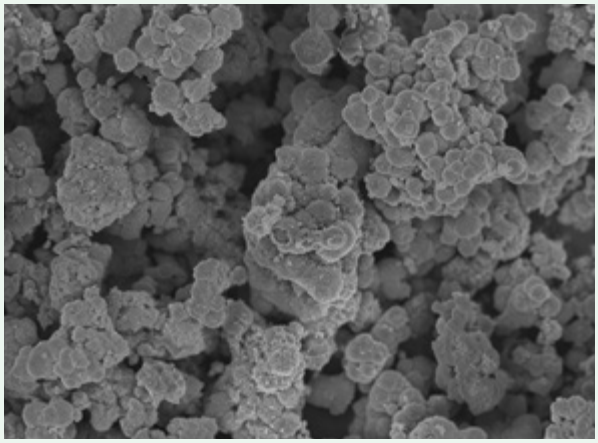
## DOUBLE-LAYER PROTECTION

We combined both approaches to develop an air filter with a double layer of protection.

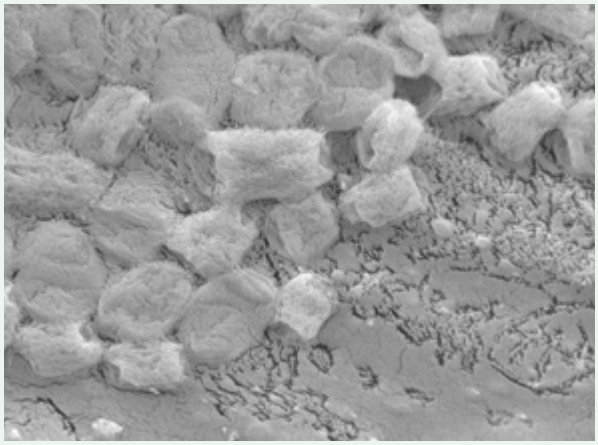
The filter was made of biodegradable silk proteins, as well as lanthanum nitrate nanoparticles which help attract and trap air pollutants and bacteria through an electrostatic effect. The filter was also coated with bacteria-killing cuprous oxide nanoparticles.

During testing, the refined air filter removed 99.9% of bacteria and tiny particles of different sizes in polluted air – from 0.3 micrometres, which is smaller than PM2.5, to 10 micrometres. The filter also killed 99.9% of multi-drug resistant bacteria in 45 seconds.

We have since commercialised our air filter and it is being used by organisations in China to filter out bacteria in hospitals. In other settings, the filter has been used to remove tiny air pollutants.



When cuprous oxide particles – pictured here under a field-emission scanning electron microscope – were coated on fabrics, the particles had an average bacterium killing efficiency of over 93%. Credit: NTU.



Field-emission scanning electron microscope image showing damaged *K. pneumoniae* bacteria on fabric, likely compromised by the coating of cuprous oxide particles. Credit: NTU.

# Taking robots at face value

## Understanding humans' emotional and facial responses to robots

By Xu Hong and her team

*Assoc Prof Xu Hong from NTU's School of Social Sciences is a psychology researcher who studies the neural mechanisms of how people perceive what they see, as well as their applications in real life and human-centric artificial intelligence (AI) systems.*

*Details of this research can be found in* Heliyon *(2024), DOI: 10.1016/j.heliyon.2024.e27977; and* Human Interaction, Emerging Technologies and Future Systems V *(2022), DOI: 10.1007/978-3-030-85540-6_34.*

With more smart city solutions being developed, our social interactions have gone beyond people to include machines, such as robots in the workplace like those in the hospitality sector, AI-powered virtual assistants with three-dimensional (3D)-animated faces, and automated driver-assistance systems in vehicles.

These encounters prompt questions about humans' underlying perceptual mechanisms at play: How do we perceive and react to different types of faces? What factors influence our sense of trust or unease when we see an artificial face? How do our facial expressions reflect our distrust of automated systems?

To explore these questions, our team conducted studies that delve into the intricacies of visual processing and trust in faces and automation. Our findings offer insights into designing automated systems, as well as the faces of robots and digital characters, that inspire trust and are perceived positively.

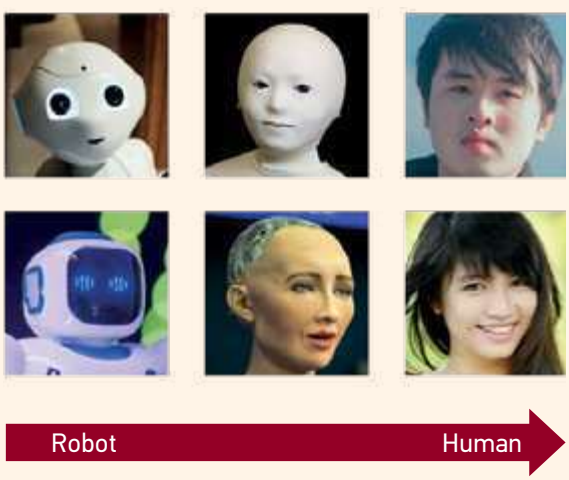
### THAT EERIE FEELING

With the rise of AI in modern society, some may wonder if humanoid robots will eventually live among us. How ready are we, as humans, to accept such robots?

One theory argues that our affinity for entities with human traits, such as androids, increases as they become more human-like in appearance. However, we are revulsed when these entities appear almost, but not quite fully, human. This revulsion, known as the uncanny valley effect, explains why some people find realistic-looking animatronics, cyborgs and mannequins eerie.

Our team explored the mechanisms behind the uncanny valley effect – a theory first described by robotics expert Masahiro Mori in 1970 that has been long debated by roboticists and scientists alike – by studying the level of visual processing required for a person to experience this phenomenon.

In a series of experiments, 111 participants were shown 91 faces that ranged from completely robotic to actual human for either 50 milliseconds (brief exposure) or three seconds (longer exposure). We asked the participants to rate each face based on how eerie they perceived it to be.




We showed participants 91 faces that vary on the robot-human spectrum, from completely robotic to almost human to actual human, for either a brief moment or a longer period. We then asked them to rate these faces based on their perceived eeriness. Credit: Pexels; Telenoid – Osaka University and ATR Hiroshi Laboratories; ITU/R.Farrell on Flickr/AI for GOOD Global Summit/CC BY 2.0.

We found that the uncanny valley effect experienced by participants was similar in both brief and longer exposure conditions. This suggests that when making sense of what they see, people consider artificial faces as eerie early in the process even if the faces are shown briefly. This feeling of unease seems to develop almost instinctively and instantaneously.

These findings shed light on how robots, androids, virtual characters and 3D AI assistants can be designed to appear less unsettling. An artificial face that has either a natural human-like appearance or a more robotic appearance is more likely to be positively perceived, and does not fall into the pitfall of the uncanny valley.

## THE FACE OF TRUST

Another factor to address in human-robot interactions is users' trust in automation technologies, such as collision detection systems in vehicles. People need to trust machines and systems in order to effectively use them.

One way to gauge users' trust in automation is by studying their facial expressions, which are made up of different movements in the muscles of the face. For example, to form a smile, we lift our cheek muscles – which creates small wrinkles around our eyes – and pull up the muscles at the corners of our lips. Together, these facial movements express happiness.

Our team sought to determine if specific facial expressions and movements could reliably indicate distrust. We examined various facial expressions of distrust and identified several combinations of facial muscle movements. These combinations were compared to the muscle movements involved in expressing the six basic emotions: anger, disgust, fear, happiness, sadness and surprise.

We found two main expressions of distrust indicated largely by the movements of the eyebrows and eyes. These two expressions are different from those of the six basic emotions based on their unique combinations of facial muscle movements.

This discovery suggests the potential of analysing facial muscle movements to detect distrust in real-time, which could be useful in developing automated systems that need high levels of users' trust.

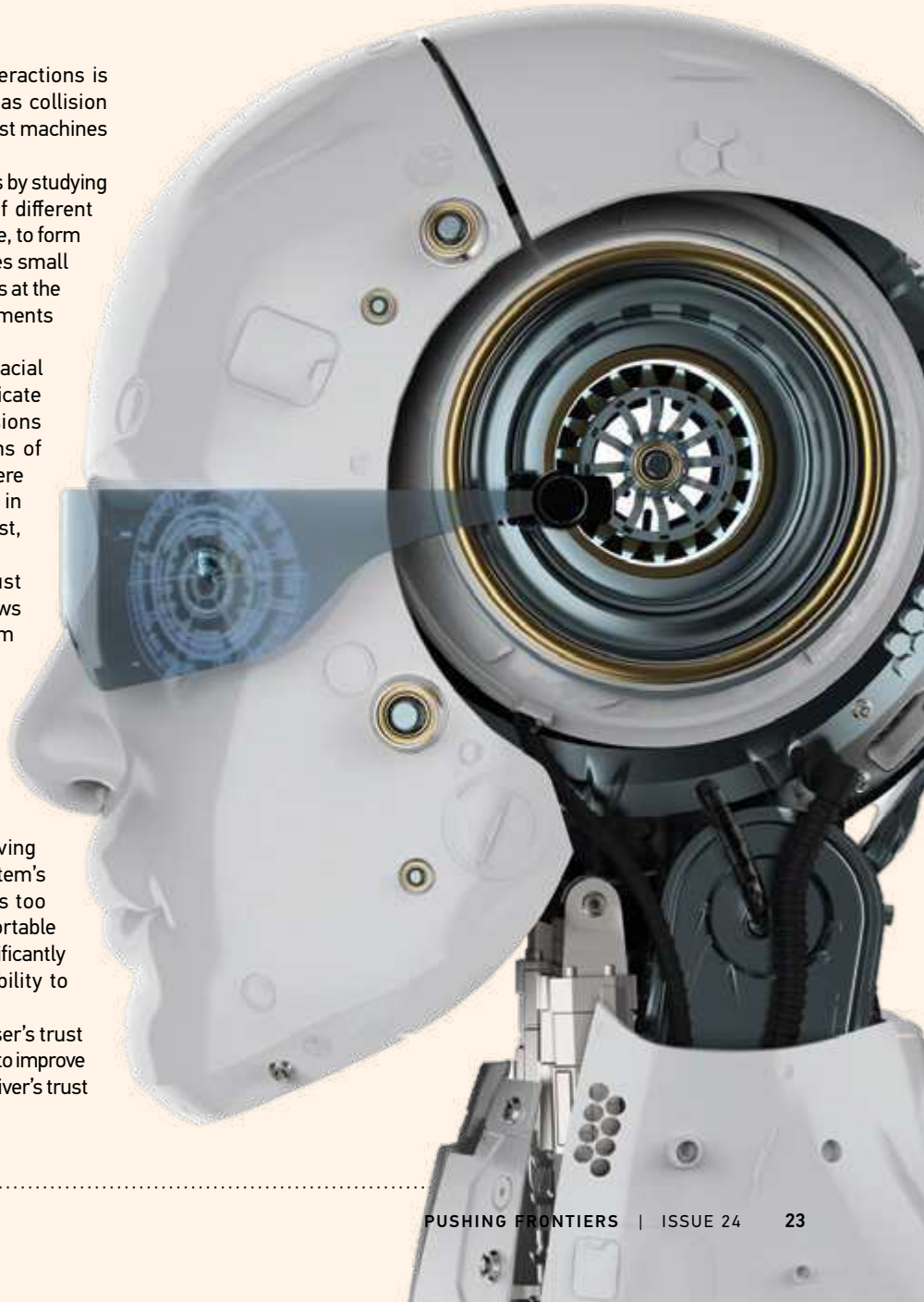
For instance, users of an autonomous driving system have varying levels of trust in it. If the system's driving behaviour, such as for lane changing, is too aggressive, some drivers might become uncomfortable with the system and even distrust it. This can significantly impact the user experience and the driver's ability to operate the vehicle safely.

However, if the system is able to detect the user's trust level from facial expressions, this data could be used to improve and adjust the system's driving style to boost the driver's trust and acceptance.

## BETTER HUMAN-ROBOT INTERACTIONS

These two studies highlight the complexity and nuances of how people perceive artificial faces and automated systems. They underscore the importance of considering people's visual and emotional responses when designing artificial entities and systems.

As we continue exploring how people understand faces, we aim to contribute towards creating more effective and empathetic human-robot interactions to improve users' experiences and how advanced technologies are perceived and accepted in society.



# Cruising into sustainable shipping

## Sparking the green transformation of the maritime industry

By Yan Ran

*Asst Prof Yan Ran of NTU's School of Civil and Environmental Engineering leverages artificial intelligence (AI) and big data to make shipping operations more efficient and environmentally sustainable. She leads the Maritime AI for Innovation, Navigation and Atmospheric Sustainability Lab, which pioneers cutting-edge maritime research and innovations in areas such as sustainable shipping and intelligent port management.*

*Details of the research can be found in* Applied Energy *(2024), DOI: 10.1016/j.apenergy.2024.123132;* Ocean and Coastal Management *(2024), DOI: 10.1016/j.ocecoaman.2024.107021; and* Transportation Research Part B: Methodological *(2024), DOI: 10.1016/j.trb.2024.102887.*

Over 80% of global merchandise trade by volume is carried by the international shipping industry, making shipping the main mode of transport for global trade. The high traffic volume results in significant emissions of pollutants and greenhouse gases. Shipping activities accounted for almost 3% of global carbon dioxide emissions in 2018, and the industry's climate footprint could increase 250% by 2050.

Using AI to analyse large amounts of maritime data can help the shipping industry reduce carbon dioxide emissions from ships. As ports are vital links between international trade and the global supply chain, it is also important to optimise port operations such as ship inspections to prevent accidents and ensure the smooth flow of goods around the world.

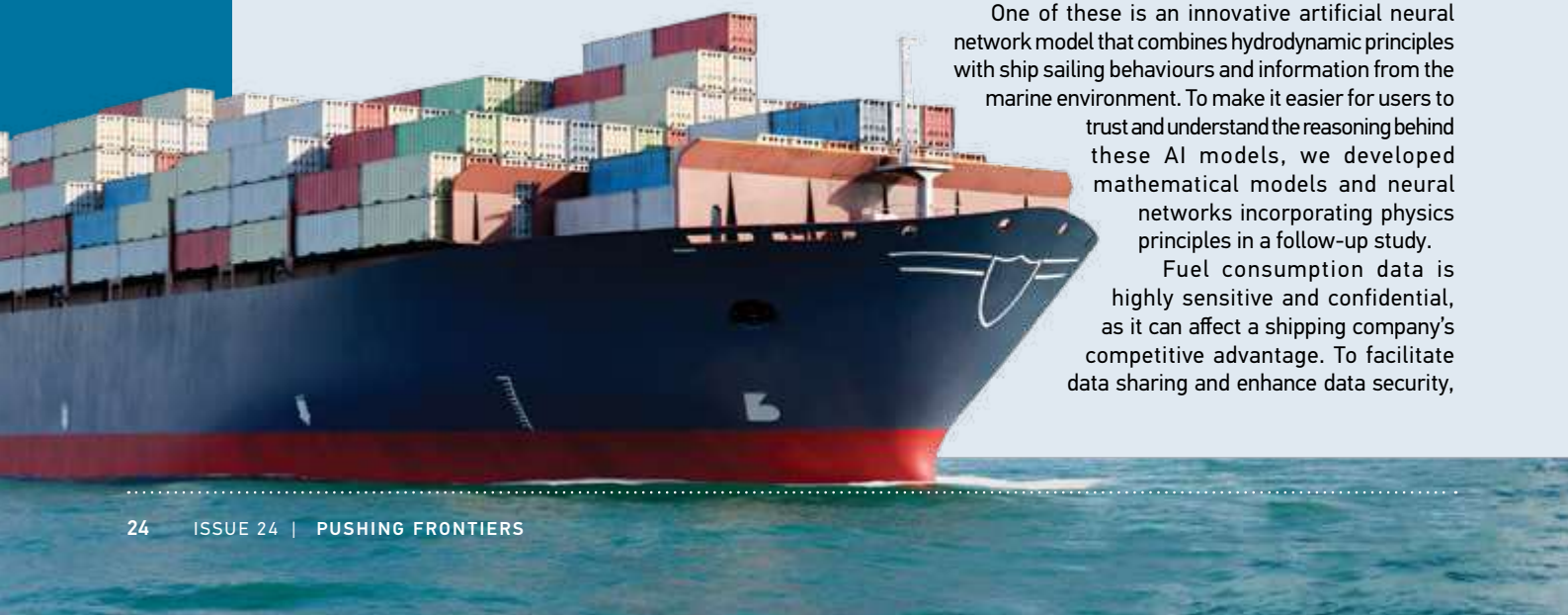
## REDUCING ENERGY CONSUMPTION AND EMISSIONS OF SHIPS

The latest international and regional regulations require ships to be more environmentally friendly, especially by adopting low-emission fuels. Accurately predicting the energy demand and fuel consumption of ships under various conditions is therefore crucial to optimising ship operations.

However, traditional methods of estimating fuel consumption are not accurate as they consider only the sailing speed of the ship and neglect other factors, such as its characteristics, as well as sea and weather conditions. To address this challenge, we developed several AI models to predict the fuel consumption of ships more accurately.

One of these is an innovative artificial neural network model that combines hydrodynamic principles with ship sailing behaviours and information from the marine environment. To make it easier for users to trust and understand the reasoning behind these AI models, we developed mathematical models and neural networks incorporating physics principles in a follow-up study.

Fuel consumption data is highly sensitive and confidential, as it can affect a shipping company's competitive advantage. To facilitate data sharing and enhance data security,



we created AI-powered fuel consumption prediction models that protect data privacy while fostering mutual trust among shipping companies.

We used the data generated by these models in different environmental conditions to optimise ship sailing behaviours, such as sailing speeds and routes based on weather forecasts. Our most recent work evaluates the environmental impact of green and digital shipping corridors involving the Port of Singapore. Using big data on shipping, we can estimate the emission reduction potential and the corresponding health and climate impacts.

## OPTIMISING PORT OPERATIONS

Efficient port operations are crucial for the timely transport of goods to international markets. Delays at ports hinder trade and other economic activities. Predicting the arrival of a ship at a port is critical to both the port authority and the goods supply chain, as it improves operational efficiency and customer satisfaction.

In another project, we combined maritime data from different sources – including ship port arrival behaviours and real-time port, sea and weather conditions – to develop state-of-the-art AI models to predict a ship's arrival at the port and its turnaround time.

Foreign ships visiting a national port are also subject to inspections of maritime safety, environmental protection and the crew's living and working conditions. The risk profile of a ship determines the type and frequency of inspection: high-risk ships are required to undergo more extensive inspection than low-risk ones.

To facilitate inspection and minimise delays, we developed several AI-powered ship risk prediction models that can assess the risk profile of a ship and identify high-risk ships that dock at the port. Together with an online decision support system that visualises the location, predicted risk levels and basic information of the ship, the models enable more informed decisions on assigning and scheduling inspections.

We are also exploring the use of drones to facilitate manual onboard inspections to reduce the workload of ship inspection officers and improve inspection efficiency.

# ENGINEERING THE CITIES OF TOMORROW

**Chair of NTU's School of Civil and Environmental Engineering Prof Chu Jian outlines why smart and sustainable cities hold the key to a liveable world.**

Prof Chu Jian is passionate about overcoming the various sustainability challenges faced by cities. The Chair of NTU's School of Civil and Environmental Engineering (CEE) and President's Chair in Civil Engineering spearheads a portfolio of research spanning from coastal protection and land reclamation to sustainable construction and waste recycling.

Prof Chu has published over 400 journal and conference papers, and holds several patents. In 2023, he was listed among the world's top 2% of scientists by Stanford University. The civil engineer's expertise has also been recognised by the International Society for Soil Mechanics and Geotechnical Engineering. He chairs the Technical Committee on Land Reclamation in the professional association.

*Pushing Frontiers* speaks to him to find out how cities can prepare for the future, and why sustainability can co-exist with urban development.

**Q** In your opinion, what are the key elements that characterise a city as sustainable and smart?

**A** A smart city is one that uses technology extensively in its operations. It is also important to design cities with smart engineering in mind. Robust structures in a smartly engineered city with high-tech infrastructure can last a long time with little maintenance. In fact, some ancient buildings are still standing today after thousands of years.

Other key ingredients that make up a smart city are a highly trained workforce, forward-looking governance and an efficient administration system that makes the best use of assets, resources – including human capital – and services.

As resources are limited, a smart and sustainable city needs to conserve the energy it uses as well as generate clean and renewable energy. It needs a clean water source and resilient food production or supply. Having a sustainable waste management system in place is also vital.

Infrastructure in a smart city should be renewed in a sustainable way. For instance, instead of replacing every worn-out component, consider replacing only some components while refurbishing the rest. Durable and self-healing materials could also be used to construct sustainable buildings that withstand the test of time.

**Q** Why are smart cities the key to a sustainable future?

**A** Densely populated cities consume a lot of resources and exert many negative effects on the environment.

A city cannot be sustainable without the renewal of smart minds. And smart cities attract a highly skilled workforce that can be mobilised to come up with solutions to sustainability issues.

To continue to attract the best talent, cities need to be regional or global hubs and stay ahead of the global competition for skilled labour. They also need to provide a conducive environment and opportunities for these highly skilled workers to apply and develop their talents.

**Q** How can cities remain sustainable?

**A** Climate change is one of the greatest challenges facing cities today and in the future. Rising global temperatures cause increases in sea levels, which may lead to coastal flooding. To reduce such risks, coastal cities like Singapore need to act early to develop and adopt coastal protection as well as flood mitigation measures.

Urban development is also constrained by the availability of space and other vital resources.

Integrated engineering solutions could be developed to address some of these sustainability challenges concurrently. These measures ensure that urban infrastructure is continually renewed to create a sustainable environment that provides a comfortable standard of living.

**Q** Tell us about the engineering innovations developed by CEE that contribute to smart and sustainable cities like Singapore.

**A** I am developing floating flexible sea walls that could be used to create coastal reservoirs that protect against flooding due to rising sea levels.

In another project, we are exploring protecting coastlines with tube-like bunds consisting of plant fibres, sand and eco-cement made from soya bean powder, calcium-rich materials and urea.

Both research projects are under the Coastal Protection and Flood Resilience Institute Singapore.

Likewise, researchers at CEE are working on projects that address urban challenges – from tapping new renewable energy sources to developing sustainable construction materials. Our faculty has led major university sustainability initiatives such as the Nanyang Environment and Water Research Institute. CEE alumni were also involved in the construction of Gardens by the Bay, an internationally acclaimed attraction in Singapore that showcases sustainability.

We also work closely with various organisations such as the National Environment Agency in Singapore in areas like sustainable waste management.

**Q** How do we strike a balance between urbanisation and sustainability?

**A** We need to be aware of the importance of sustainability so that urban development does not come at its expense.

Contrary to popular belief, sustainability and urbanisation do not contradict each other. There are many buildings and places in Singapore that illustrate sustainable urbanisation. One example is NTU's School of Art, Design and Media building, which has several eco-friendly features, including "grass roofs" that reduce heat gain. At Gardens by the Bay, "supertrees" collect rainwater for irrigation and generate solar energy.

Other innovative ways to balance urbanisation with sustainability include developing underground space and installing sea walls with provisions for intertidal zones to maintain biodiversity.

**Q** What role can NTU play in creating sustainable solutions to address urban challenges in Singapore and around the world?

**A** NTU is a leader in sustainability. In addition to creating innovations for sustainable urban development, NTU has set a goal to be carbon neutral by 2035.

Currently, there are eight zero-energy buildings on the NTU campus that consume as much energy as they produce. These zero-energy buildings make up about two in five of the total number of certified zero-energy buildings in Singapore, making NTU the greenest campus in Singapore.

Now that NTU has established the nuts and bolts of urban sustainability, it is time to look at the bigger picture and focus on putting these innovations together to drive comprehensive sustainability solutions for the region and beyond.

**"Robust structures in a smartly engineered city with high-tech infrastructure can last a long time with little maintenance."**

# CONFRONTING CLIMATE CHANGE

**Innovative approaches are needed to tackle the climate problem before it is too late, says Earth Observatory of Singapore director Prof Benjamin Horton.**

Southeast Asia is now better prepared for natural hazards like earthquakes since the Earth Observatory of Singapore (EOS), an NTU research centre, was set up in 2008. But what if a quake strikes in the midst of a heatwave caused by climate change?

EOS will increasingly have to tackle issues like this one, says the centre's director, Prof Benjamin Horton. An AXA-Nanyang Chair in Natural Hazards, Prof Horton is also a Professor of Earth Science at NTU's Asian School of the Environment (ASE). He has been studying sea level rise for over 25 years. He is the lead investigator of the Climate Transformation Programme, launched by NTU in December 2023 and hosted by EOS to conduct interdisciplinary climate research.

From 2018 to 2021, he was an editor for the Sixth Assessment Report of the United Nations' Intergovernmental Panel on Climate Change, and is now involved in developing the next report. He also led Singapore's first scientific mission to Antarctica in February 2023.

Prof Horton shares his views on climate change and EOS's work in this *Pushing Frontiers* interview.

**Q** What is the biggest environmental challenge cities face?

**A** The key challenge for cities is their lack of resilience to the threats of climate change, be they rising temperatures, rainfalls or sea levels. The hazards cities face like flooding and heatwaves are exacerbated by climate change, more people migrating to cities daily and cities not well equipped to manage all this. By finding ways for cities to function sustainably, we will help the Earth function sustainably too.

**Q** Why is this challenge a problem for Singapore?

**A** For any island nation, sea level rise from melting ice sheets is an existential threat. A third of Singapore's coastline is just above the highest of high tides. So any change in sea levels has a dramatic impact. And in Singapore, you cannot move inland. Other climate risks include the impact of extreme rainfall on critical infrastructure, heatwaves on outdoor jobs and droughts that affect Singapore's trade and security.

**Q** How has EOS's role evolved over the years in the wake of climate change?

**A** EOS was set up after the highly destructive 2004 Indian Ocean tsunami to better understand the processes that cause devastating earthquakes and volcanic eruptions. Over the past 15 years, the centre has improved the resilience of cities, ecosystems and rural areas in Southeast Asia to earthquakes, volcanic eruptions and tsunamis, as well as climate change.

With 170 monitoring stations in eight countries, we can now better forecast future natural hazards, such as the size and frequency of earthquakes. As the climate change threat became more urgent, EOS pivoted towards addressing issues like how high sea levels will rise and how hot urban areas will be. We must now also think about compound hazards, like when earthquakes strike during heatwaves.

**Q** What is one notable EOS study on climate change?

**A** Cheryl Tay, a Singaporean PhD student at EOS and ASE, used innovative satellite imagery to identify the rate at which the 50 largest cities in the world are sinking. Cities sinking the fastest are most susceptible to rising sea levels linked to climate change. A paper on this was published in 2022.

Although international organisations were studying other issues of sea level rise, none were looking into sinking lands. So, Cheryl quickly became a world-leading expert on the matter.

**Q** What is the most startling discovery about sea level rise that you have made?

**A** Scientists previously believed that sea levels had risen more quickly than before but had no supporting data. Ten years ago, my team found accurate records from geological data going back thousands of years that proved the 20th century's rise in sea levels was unprecedented and driven by human activity. We identified that the rate of sea level rise since the industrial revolution in the 1850s was faster than anything we had seen for the past 2,000 years.

The discovery was so important that then-United States president Barack Obama cited it in his State of the Union Address in 2015.

**Q** How is EOS tackling the anticipated problems of climate change?

**A** Climate research is moving increasingly into issues such as a changing climate's impact on temperatures and rainfall, and the knock-on effects in areas like biodiversity, finance and healthcare. It means figuring out how to monitor these impacts with innovative methods, such as artificial intelligence and remote sensors located far away, as well as involving regional stakeholders and interdisciplinary researchers.

That is the basis of the new flagship Climate Transformation Programme that NTU launched, which is funded by Singapore's Ministry of Education.

**Q** How is the Climate Transformation Programme different from other climate studies?

**A** The programme is not just based on traditional science, technology, engineering and mathematics disciplines. We are including the social sciences, humanities and the arts for people and the economy too.

We are thinking about how we can get policymakers and public-private partnerships to understand the impacts of a changing climate on areas like healthcare and financial systems. For example, we are studying the effects of El Niño such as higher temperatures, worsened by climate change, on financial markets in Southeast Asia.

We are also thinking about how we can better communicate the impact of climate change through mediums like film and sound, while studying issues such as climate misinformation.

These efforts are important because the status quo of authoring climate change academic papers and policy reports to get people to act has not worked. We can find suitable solutions only by agreeing to act together. We must first create a shared narrative on tackling the climate crisis, where the social and economic benefits are clear.

Second, we need to build trust and improve communication between sectors, regions and communities involved in climate action, and strengthen accountability for commitments to net-zero emissions.

Third, and most importantly, we must link those most responsible for environmental damage to those most affected by it.

**"We must link those most responsible for environmental damage to those most affected by it."**

# BUILDING INTELLIGENT INFRASTRUCTURE

## HIGH-TECH INNOVATIONS FOR SMART LIVING

*Pushing Frontiers* highlights three pioneers who are leading the way in applying the latest advancements to design friendlier self-driving cars, manufacture creative structures and plan functional neighbourhoods.

ASSOC PROF

# PEER SATHIKH

*INDUSTRIAL AND INTERACTION DESIGN*


Credit: NTU.

Many artificial intelligence (AI) assistants can now speak in more natural-sounding voices. But users may still find them awkward as their speech often lacks context and the appropriate emotional tones of a real person.

Industrial designer Assoc Prof Peer Sathikh from NTU's School of Art, Design and Media (ADM) wants to change that by developing more personable and relatable AI assistants that have a persona for self-driving cars. This would help people feel at ease when interacting with them.

"For passengers to consider using an autonomous vehicle, they need to trust the technology. If people can interact with the vehicle's AI naturally, this may improve their trust in it," says Assoc Prof Sathikh, who is also Director for Industry Engagement and Cross-Collaboration at NTU's College of Humanities, Arts and Social Sciences.

To this end, he is working with other NTU researchers to train OpenAI's ChatGPT and Anthropic's Claude AI to speak more naturally, like how typical taxi drivers in Singapore would interact with a passenger. The AI assistants will be capable of adjusting their tone and choice of words in response to a passenger's mood and circumstances.

Assoc Prof Sathikh's research on refining people's experience with AI interactions stems from his interest in improving how people interact with different things through design, especially in transport.

For example, Assoc Prof Sathikh's design inputs shaped office workflows within the metro control centres in Singapore, Thailand and India. He optimised the seating arrangement of the personnel managing train traffic to improve how they communicate within and between teams, while being alert to train movements and happenings in the stations.

He is keen on infusing culture into design too. He worked with a former colleague to incorporate Islamic and historical elements into a garden in Iraq that filters wastewater before it flows into the Tigris and Euphrates rivers. The project, called Eden in Iraq, is in the process of being realised.

Besides teaching design at NTU, Assoc Prof Sathikh has held positions on advisory committees to guide the development of design courses at Ngee Ann Polytechnic and Nanyang Polytechnic. For his contributions to design education, he was awarded Singapore's Public Administration Medal (Bronze) in 2022.

From 2003 to 2005, Assoc Prof Sathikh was the President of the Designers Association Singapore, a multidisciplinary design organisation now known as the Design Business Chamber Singapore.

He led association members in a voluntary effort to find design solutions to combat the severe acute respiratory syndrome (SARS) outbreak in 2003. Many of the association's recommendations, such as protective gear for healthcare workers and a colour code to show the severity of SARS outbreak, came in handy during the COVID-19 pandemic in 2020.

The association was recognised for its efforts in combating the SARS outbreak at a special ceremony in 2003, receiving a Certificate of Commendation from the President of Singapore.

A serial entrepreneur, Assoc Prof Sathikh co-founded Singapore-based design consultancy Inovasia Design in 1996. In 2007, he co-founded Teknovate in India, an injection moulding company that specialises in producing critical parts for the automobile industry.

Assoc Prof Sathikh also helped set up the Garage@ADM initiative at NTU, which supports ADM graduates in starting business ventures.

"I'm always thinking about what's new in technology and what's new in human behaviour. We're now in the AI era. Are we ready for what's next?" asks Assoc Prof Sathikh.

Credit: NTU.

PROF

# YEONG WAI YEE

*3D PRINTING AND BIOPRINTING*

"I first became interested in 3D printing when I was an undergraduate. I decided to do my PhD in the 3D printing of scaffolds for tissue engineering, a topic which marries two of my favourite subjects – 3D printing and medical technology."

Prof Yeong Wai Yee has come a long way. The 3D printing enthusiast has forged new paradigms in bioprinting and is now the Chair of NTU's School of Mechanical and Aerospace Engineering (MAE), where she leads revolutionary research initiatives in areas such as advanced manufacturing, aerospace, engineering and robotics.

Before becoming Chair of MAE, Prof Yeong was the programme director of the aerospace and defence research pillars of the Singapore Centre for 3D Printing (SC3DP), a research centre in MAE that advances the science and technology of 3D printing.

SC3DP and MAE are at the forefront of using these technologies to develop solutions for smart and sustainable cities. For instance, the National Additive Manufacturing Innovation Cluster at SC3DP collaborated with local drone services provider Flare Dynamics to enable printing of the electronic circuit on the protective cage enclosure of drones. This innovation eliminates the use of wires to power the sensor system of drones, reducing their weight and facilitating their maintenance.

One notable research focus at MAE is on electric vertical take-off and landing (eVTOL) aircraft. The school has partnered with intelligent power management company Eaton to develop innovative eVTOL solutions for sustainable air travel.

Other 3D printing innovations developed at SC3DP and MAE include 3D printable cement made from industrial by-products and a 3D-printed bathroom. MAE is also home to inventions such as a paint that keeps buildings cool, a fungi-based biomaterial that resembles elephant skin and a technique that converts paper waste into a vital component in lithium-ion batteries.

Prof Yeong was part of the team that secured funding to set up the HP-NTU Digital Manufacturing Corporate Lab – a collaboration between NTU, HP Inc. and the National Research Foundation, Singapore. Currently, she is the programme director of the 3D printing research domain at the lab, which supports Singapore's push towards industry transformation in the areas of digital manufacturing and 3D printing technologies.

For her contributions to 3D printing, Prof Yeong was honoured with the first TCT Women in 3D Printing Innovator Award in 2019. The accolade celebrates female pioneers in 3D printing and additive manufacturing.

In 2021, the Singapore Computer Society in partnership with SG Women in Tech and the Infocomm Media Development Authority in Singapore named Prof Yeong as one of the Singapore 100 Women in Tech honourees. The list features inspiring women who have contributed to Singapore's tech industry. Three years later, she was recognised with the Top 50 Asia Women Tech Leaders award.

Prof Yeong has also served as a reviewer for the Advanced Grants awarded by the European Research Council.

"The applications of 3D printing are limitless and the technology enables endless creativity in design. My curiosity to explore the potential of 3D printing keeps me motivated in my research," says Prof Yeong.

An expert in information systems, Prof Goh Kim Huat is experienced in using analytics and economic theories to model human behaviour in healthcare and technology-mediated settings as well as to evaluate the implementation of health systems. He has worked with various local and international organisations on business analytics-related projects and has published several papers in top-tier information systems journals.

One of Prof Goh's recent projects was to develop a city scanning tool. The tool detects trends, identifies deviations, as well as predicts and validates relationships between various parameters across different zones of a city.

"My expertise in information systems coupled with an interest in social sciences came in handy for the development of this tool that leverages big data to monitor the health of a city," says Prof Goh, who is Associate Dean (Graduate Studies) at NTU's Nanyang Business School. He is also Senior Editor of Journal of the Association for Information Systems.

The project – jointly led by NTU, the National University of Singapore and Singapore's Agency for Science, Technology and Research – is a collaboration with the National University Health System, Mastercard and DataSpark, a subsidiary of telecommunications conglomerate Singtel in Singapore.

The research was supported by the National Research Foundation, Singapore, and the Ministry of National Development, Singapore, under its Cities of Tomorrow R&D Programme.

To construct the framework, Prof Goh and his team partnered with organisations and government agencies to collect data in Singapore, spanning societal, health, attitudinal, economic and environmental dimensions. Examples of data collected include spending patterns, the number of hospitalisations due to different ailments, human traffic volume and sentiments in public feedback to the government. The data ranged from static information to semi-dynamic data and highly dynamic data.

The data was anonymised and aggregated before being analysed and combined into a "data cube" that could be used to detect emerging trends and deviations across different zones in the city.

This tool could alert policymakers drawing up plans for the city to potential outliers or red flags in a city, such as traffic congestion and epidemics. For urban planners, the tool helps them understand the character, vibrancy and activities of the various parts of the city, enabling them to design neighbourhoods that cater to the unique and evolving needs of the residents.


Credit: NTU.

For instance, the tool can help create dementia-friendly neighbourhoods. Alzheimer's disease is a common form of dementia, and individuals with cardiovascular diseases are more likely to develop the condition. By analysing the correlations between both diseases, the tool can identify subzones where residents face a higher risk of Alzheimer's disease, along with the environmental, social and economic factors that may exacerbate the development of the condition.

The project's findings were published in a paper that won the Best Short Paper Award at the 2022 International Conference on Information Systems. Singapore's public housing agency, the Housing and Development Board, is looking to implement the tool in its town planning.

Prof Goh is also developing algorithms to improve how resources are allocated for community health, and studying the acceptance of artificial intelligence in healthcare.

PROF

## GOH KIM HUAT

*INFORMATION SYSTEMS*

# EMBRACING CHANGE, INNOVATION AND DIVERSITY

Three emerging artists from Southeast Asia displayed original works in video, sound and virtual reality at an exhibition under **SEA AiR – Studio Residencies for Southeast Asian Artists in the European Union**, an art programme developed by the NTU Centre for Contemporary Art (CCA) Singapore and funded by the European Union (EU). The exhibition, which ran for nearly two months until January 2024, concluded the second cycle of SEA AiR and was part of Singapore Art Week 2024.

Inspiring creativity through cultural exchange: (clockwise from top left) Screenshot of the working process for Priyageetha Dia's sound installation *Sap Sonic*, image from Ngoc Nau's video installation *Virtual Reverie: Echoes of a Forgotten Utopia* and video still from Saroot Supasuthivech's multimedia installation *Spirit-forward in G Major*. Credit: Priyageetha Dia, Ngoc Nau and Saroot Supasuthivech. Courtesy of CCA Singapore.

Titled Passages, the exhibition featured works by Priyageetha Dia, Ngoc Nau and Saroot Supasuthivech, artists from Singapore, Vietnam and Thailand respectively. The trio was selected by SEA AiR to undertake art residencies in Europe.

Using new media technologies, the artists created speculative narratives that traversed time and space. Their works for the exhibition were inspired by their time in Europe and reflected their journeys across geographical and cultural boundaries, cultural exchanges and continuous development of ideas as they returned to their home countries.

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In November 2023, 120 participants from over 15 countries gathered at the **18th APRU Multi-Hazards Symposium** to discuss the challenges and solutions associated with natural hazards and climate change. The symposium was hosted by the Earth Observatory of Singapore at NTU, in collaboration with the Association of Pacific Rim Universities (APRU) – a consortium of 61 universities around the Pacific Rim.

Centred on advancing disaster risk science, technology and policy, roundtable discussions at the symposium fostered exchanges on topics such as strategies to translate science into policy as well as risk communication.

The symposium concluded with visits to places in Singapore that showcased the sustainability efforts of NTU and the nation.

Addressing natural hazards and climate change: Symposium participants learnt about the importance of embracing sustainability concepts. Credit: Earth Observatory of Singapore.

Over 60 startups, spinoffs and promising innovations were showcased at a **technology roadshow** in October 2023. They were among the 330 startups and deep-tech spinoffs that the University has successfully incubated in less than a decade.

Organised by NTUitive, NTU's innovation and enterprise company, the public event at NTU marked the beginning of the next phase of the University's initiative to create high-quality startups and nurture entrepreneurial mindsets.

Among the startups featured were ACM Biolabs, a biotechnology firm with a proprietary nanoparticle delivery platform to create vaccines and drug-delivery systems; MindSigns Health, which uses a cloud-based platform to analyse electroencephalogram waveforms for patients with epilepsy or life-threatening neural conditions; and VFlowTech, which produces longer-lasting, safer and more affordable batteries.


Launching the technology roadshow: (from left) Mr Chew Sutat, NTUitive board member and Chairman of Shan De Advisors Pte Ltd; Mr David Toh, NTUitive's CEO; guest of honour Ms Low Yen Ling, Singapore's Minister of State for Trade and Industry, and Culture, Community and Youth; Prof Louis Phee, NTU's Vice President (Innovation and Entrepreneurship); and Dr Stanley Lai, NTUitive board member and Partner at Allen & Gledhill LLP. Credit: NTU.

The biennial **Lien International Conference on Good Governance** in August 2023 brought together scholars, practitioners and researchers from Singapore and abroad to discuss issues related to public governance, public service delivery and evaluation. Themed Good Governance for the Common Good, the conference attracted more than 300 scholars, experts and researchers from over 20 countries. It was organised by the Nanyang Centre for Public Administration (NCPA) and Lien Ying Chow Legacy Fellowship.

The guest of honour, Minister for Communications and Information in Singapore Mrs Josephine Teo, spoke about the importance of digital governance and the need to invest in future-proofing the digital infrastructure as technology evolves.


In his opening speech, Prof Liu Hong, Associate Vice President (International and Coordination) and NCPA Director (Research and Executive Education) gave an overview of the conference and shared the progress made in teaching and research over the past three decades. Credit: NCPA.

In May 2024, the Centre for Lifelong Learning and Individualised Cognition (CLIC) at NTU launched a book titled ***Neurodiversity: No Brain Is the Same*** that features artworks by special needs students in Singapore.

These artworks are entries in an art competition that were exhibited at a public science festival, **The Brainiverse Experience**, held at the ArtScience Museum in Singapore. Organised by CLIC, the festival showcased CLIC's research on learning and mental wellbeing.

Celebrating neurodiversity: (from right) Marisha Ubrani, research assistant at CLIC and organiser of the art competition, explaining the artworks by special needs students in Singapore to Mr Beh Kian Teik, CEO of NRF Singapore; Prof Shirley Ho, NTU's Associate Vice President (Humanities, Social Sciences and Research Communication); and CLIC co-director Prof Annabel Chen. Credit: NTU.

# COMING YOUR WAY

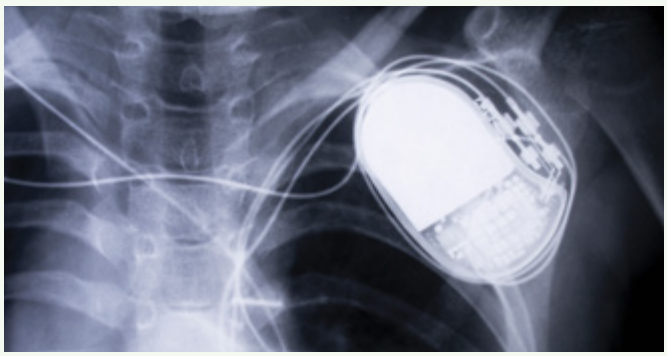
**1** The **Singapore-CEA Alliance for Research in Circular Economy** will scale up electronic waste recycling projects alongside industry partners with an additional S$20 million (US$26.6 million) in funds from Singapore's National Environment Agency, NTU and the French Alternative Energies and Atomic Energy Commission (CEA).

The renewed funding for the joint research centre between NTU and CEA was among six partnerships NTU formed with French partners at the third meeting of the Singapore-France Joint Committee on Science and Innovation, which works towards boosting science and technology research.

Collectively, the partnerships expand ties linking NTU with the French organisations to push the boundaries of science across multiple fields: quantum physics, nuclear energy, satellite engineering, remote sensing, sustainability, artificial intelligence, machine learning and neural networks.

**2** To address the security concerns of healthcare institutions, such as the risk of Internet-connected medical devices being targeted by hackers, NTU and Imperial College London have partnered to launch the **IN-CYPHER research programme**.

The S$20 million (US$15.4 million) initiative is funded by the National Research Foundation, Singapore. It will look into improving the security of medical devices and health data, including developing better ways to protect devices implanted for diagnostic or therapeutic purposes, such as pacemakers, as well as safeguard the data of connected wearables and healthcare systems.



**3** To cut the operation costs and environmental impact of energy-guzzling data centres, NTU and the National University of Singapore (NUS) are jointly leading the world's first testbed in the tropics to advance energy-efficient data centre cooling solutions.

Funded by the National Research Foundation, Singapore, the **Sustainable Tropical Data Centre Testbed** is now up and running, and has attracted more than S$30 million (US$23 million) in investments. The centre aims to fast-track the adoption of cooling technologies that reduce energy and water use, alongside carbon emissions, by up to 40%.

Singapore's Minister of State for Trade and Industry Mr Alvin Tan (left) touring the new Sustainable Tropical Data Centre Testbed. Credit: NUS.

**4** Autonomous technologies for vessels and unmanned vehicles are the focus of two research tie-ups between **NTU** and **Naval Group Far East**, a subsidiary of French shipbuilder Naval Group.

The first project seeks to develop a semi-autonomous vessel navigation system that automates path planning to avoid collisions. The second one focuses on an artificial intelligence-powered mission planning tool that could allow unmanned vehicles to work together and alter their course of action in real time when responding to emergencies.

These technologies could be used in areas such as navigating vessels, search and rescue missions, environmental monitoring, and naval operations.

**5** Research under the new **ExxonMobil-NTU-A*STAR Corporate Lab** is set to contribute to Singapore's energy security, unlock new socio-economic potential and help support the country's progress towards a net-zero future.

The S$60 million (US$46 million) lab was established by ExxonMobil Technology and Engineering Company, NTU and Singapore's Agency for Science, Technology and Research (A*STAR).

The lab will advance research in lower-emissions technologies such as converting biomass like oil palm waste into greener and potentially cost-efficient fuels with lower greenhouse gas emissions for the aviation, maritime and chemical sectors.

(From left) Asst Prof Roland Tay and Vice President (Industry) Prof Lam Khin Yong from NTU; Singapore's Deputy Prime Minister, Mr Heng Sweet Keat; and Nanofilm Founder and Executive Chairman Dr Shi Xu at the launch of the NTI-NTU Corporate Laboratory. Credit: NTU.

**6** NTU has teamed up with one of its spinoff companies, Nanofilm Technologies International, to launch the **NTI-NTU Corporate Laboratory** to research next-generation nanotechnology solutions. The S$66 million (US$50.7 million) corporate lab's work is expected to benefit many industries, from consumer electronics and automotive to biomedical and clean energy.

The lab will tap the proprietary technologies and core competencies of Nanofilm – the first local deep tech unicorn to be listed on the Singapore Exchange – in research and development to make headway in areas such as nanofabrication technologies and hydrogen energy research focused on fuel cells.

**7** Current research on respiratory diseases has largely been Euro-centric, with a knowledge gap in understanding such conditions among Asians.

At **The Academic Respiratory Initiative for Pulmonary Health Centre for Respiratory Research Excellence**, spearheaded by NTU's Lee Kong Chian School of Medicine, scientists are looking to improve the lung health of Singaporean and Asian patients with personalised treatments.

Therapies for chronic respiratory conditions that the new centre will delve into include those for asthma and chronic obstructive pulmonary disease.

**8** Businesses and financial institutions are facing new challenges from climate change and rapid technological advancements. The **Centre for Sustainable Finance Innovation**, launched by NTU's Nanyang Business School, seeks to address such issues by working with industry partners, like the London Stock Exchange Group, to promote academic research in sustainable finance and financial innovation.

The centre focuses on how environmental challenges have led companies to transition to sustainable growth, as well as the capital and investment changes that come with these shifts. It is also studying how financial innovation arising from technological progress can be achieved prudently and sustainably.

NTU's Singapore Centre for 3D Printing can print orthopaedic implants made from titanium-tantalum that is customised to a patient's unique anatomy, which reduces the amount of surgical time in hospital. Credit: NTU.

**9** A new joint research and development laboratory in additive manufacturing has been set up by **NTU** and **Singapore General Hospital** to advance 3D printing in healthcare, such as by developing customised medical devices and implants for the hospital's patients. The partnership involves NTU's Singapore Centre for 3D Printing and the hospital's 3D Printing Centre.

The new centre will focus on four areas: 3D printing prosthetics and orthotic devices to support weakened or misaligned body parts; 3D printing living tissues; 3D printing medical implants; and building 3D printing capabilities for practical healthcare applications.

# THE HONOUR ROLL

## Tech titan

**Prof Yeong Wai Yee**, the first female Chair of NTU's School of Mechanical and Aerospace Engineering, has been hailed as one of the Top 50 Asia Women Tech Leaders of 2024. The inaugural award recognises Prof Yeong's pioneering technology-driven biomedical research that aims to develop electronic implantable devices that can treat diseases and replace failing organs.

## Young science trailblazer

The European Molecular Biology Organisation (EMBO) feted **Nanyang Asst Prof Anna Barron** from NTU's Lee Kong Chian School of Medicine with the EMBO Global Investigator Award, which was given to only 10 scientists in 2023. The award comes under an initiative that fosters collaboration and networking among young science leaders in Chile, India, Singapore and Taiwan.

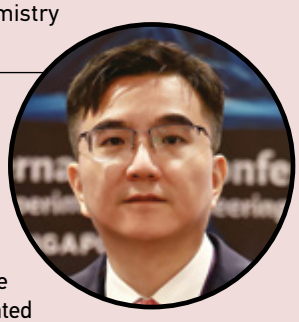
## Information systems champion

**Assoc Prof John Dong** from the Nanyang Business School was one of only six recipients of the 2023 Association for Information Systems Mid-Career Award. The accolade recognises mid-career individuals who have made outstanding research, teaching or service contributions to the field of information systems. Award winners must have also demonstrated high levels of professional and personal integrity.

## World's most influential researchers

Clarivate's Highly Cited Researchers list for 2023 recognised 42 NTU researchers who have significant and broad influence in their fields. For the sixth year running, the University had the largest number of influential scientists honoured among Singapore institutions. NTU placed 22nd globally for the number of its scientists mentioned in the list, which included (first from left) academic leaders **Prof Joseph Sung** (clinical medicine), **Prof Lee Pooi See** (cross-field) and **Prof Madhavi Srinivasan** (cross-field). Two NTU researchers were also among the 238 acknowledged globally for their work in two research areas – **Prof Jason Xu** and **Prof Pu Kanyi** (chemistry and materials science for both).

## Outstanding physics fellow



The American Physical Society in 2023 named **Prof Zhou Kun** from the School of Mechanical and Aerospace Engineering a Fellow of the Society. He was honoured for his pioneering work in improving the mechanical properties of materials, which has addressed challenges in additive manufacturing and mechanics, among other areas. He was also appointed a member of the European Academy of Sciences' Division of Physics in 2024.

## Exceptional national scientists

The Singapore National Academy of Science has inducted three NTU researchers as Fellows: **Prof Lim Kah Leong** from the Lee Kong Chian School of Medicine; **Prof Zhao Yanli** from the School of Chemistry, Chemical Engineering and Biotechnology; and **Prof Shen Zexiang** from the School of Physical and Mathematical Sciences and the School of Materials Science and Engineering. Fellows advise and contribute to the Singapore government and other national organisations on various aspects of science.

NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

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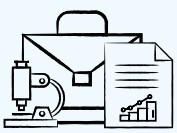

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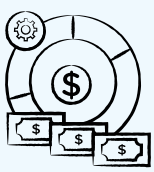

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*or*

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*or*

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