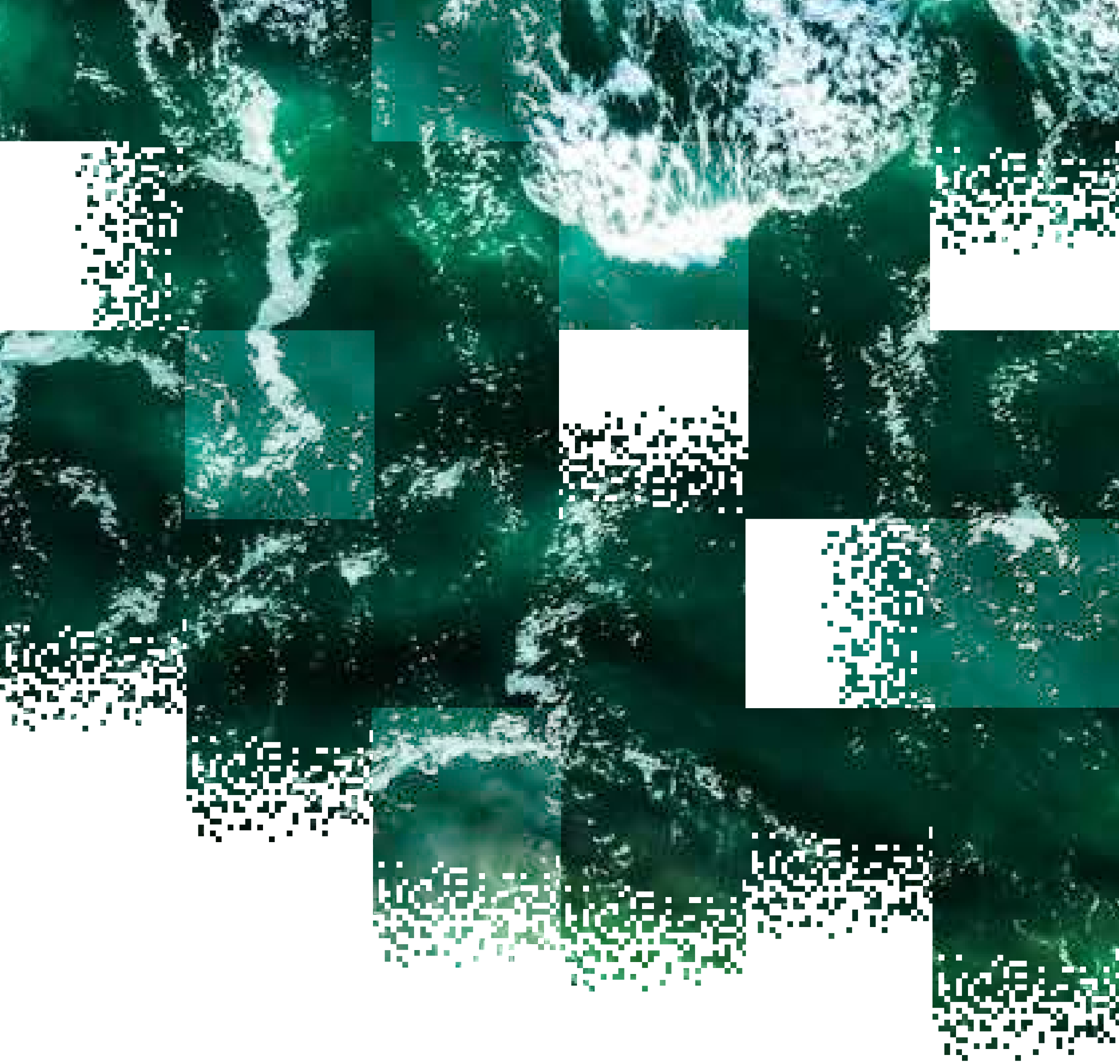

Coastal Protection and Flood Resilience Institute (CFI) Singapore

NUS National University of Singapore

Coastal Protection and Flood Resilience Institute Singapore
College of Design and Engineering

CFI SINGAPORE

Climate change is driving more extreme weather with more intense rainfall.

As an island, Singapore is particularly vulnerable to sea level rise, due to its geographical location and low-lying land area — about 30% of land surface is less than five metres above mean sea level. Without a robust coastal protection system in place, severe flooding events could bring about devastating consequences, affecting essential services and critical infrastructure.

The Coastal Protection and Flood Resilience Institute (CFI) Singapore was launched as the nation's first Centre of Excellence dedicated to strengthening local capabilities and expertise in coastal protection and flood management research and solution development.

CFI Singapore is a key pillar under PUB, Singapore's National Water Agency's S$125 million Coastal Protection and Flood Management Research Programme (CFRP), which galvanises research and technology development in coastal protection and flood management.

Established as a multi-institutional, inter-disciplinary research centre, CFI Singapore brings together the strengths of various local universities, research institutes and industry partners.

As the host of CFI Singapore, the National University of Singapore (NUS) works closely with Nanyang Technological University (NTU), Singapore University of Technology and Design (SUTD), Singapore Institute of Technology (SIT), and the Agency for Science, Technology and Research (A*STAR) to achieve the institute's key missions:

- Generate core knowledge in coastal science
- Conduct use-inspired research for coastal protection and flood management solutions for urban and land-scarce coastlines
- Collaborate to foster research ecosystem including local and international universities, research institutes and industry partners
- Train a new generation of leaders, researchers and practitioners for coastal protection and flood management

CFI Singapore's core and applied research is categorised into two horizontal domain areas (H1 and H2) and two vertical domain areas (V1 and V2).

H1 aims to inform the design of future-proof coastal structures by developing reliable design parameters that anticipate the impacts of climate change on coastal and rainfall processes.

H2 focuses on harnessing big data and machine-learning models to improve predictive systems for coastal and inland water events, enhancing accuracy of weather forecasts and bolstering early-warning systems for emergency response.

Meanwhile, V1 focuses on developing novel coastal defence structures, emphasising adaptive, multi-functional and modular designs that integrate into existing infrastructure. This domain area aims to enhance resilience, minimise land use and establish new local design standards tailored to specific coastal dynamics and flood risks.

V2 leverages nature-based approaches to create robust, resilient hybrid solutions for coastal protection, which involves developing guidelines so they can be implemented, maintained and monitored over the long term.

Additionally, CFI Singapore will also assist PUB in proposing research focus and topics for applied research grant calls.

Coastal Protection and Flood Management Research Programme (CFRP) Research Framework

Horizontal 1 | Coastal Science Research
H1 C

- Coastal processes (waves, current, storm surge, sediment transport)
- Extreme event (coupling of intense rainfall runoff and extreme sea levels, joint probability, events attribution)

Vertical 1 | Innovative Engineering Solutions for CP and FM
V1 C A

- Technologies for integrated infrastructure
- Construction techniques in deep waters
- Structural integrity

Vertical 2 | Integrated Nature-based Solutions for CP
V2 A

- Adaptive 'green-grey' hybrid solutions and large-scale testbed
- Framework for long-term monitoring
- Design criteria

Vertical 3 | Sustainable Infra Solutions for CP and FM
V3 A

- Low-carbon materials
- Lightweight, high-strength, corrosive-resistant materials
- Sustainable construction methods

Vertical 4 | Smart Management Solutions for CP and FM
V4 A

- Smart ops and emergency response
- Predictive ops of tidal gates and pumping stations
- Smart system for structural health monitoring

Horizontal 2 | Monitoring, Prediction and Digitalisation of Coastal Environment
H2 C A

- Next-generation sensing technology
- AI, machine learning and physics-informed analytics to process data streams
- Cyber-physical predictive systems to couple advanced numerical simulation research

Horizontal 3 | Integrated and Adaptive Planning
H3 A

- Integrated coastal and urban planning tools
- Systems-level planning framework
- Social science research
- Flood loss curves
- Risk quantification

CP Coastal Protection **FM** Flood Management (C) Core research (A) Applied research

RESEARCH

Coastal Science Research

- High-confidence design parameters for coastal processes
- Impact of climate change on coastal processes
- Impact on coastal protection measures

Integrated Nature-based Solutions

- Develop novel hybrid solutions
- Establish planning guidelines and engineering parameters for hybrid solutions
- Innovative approaches to implement
- Develop science-based monitoring and maintenance approaches

Monitoring, Prediction and Digitalisation of Coastal Environment

- Enhance predictive systems for coastal processes
- Enhance Singapore's convective rainfall prediction
- Enhance predictive systems for runoff generation

Innovative Engineering Solutions

- Adaptive, multi-functional and integrated solutions
- Develop local design standards

Tranche 1 projects (2023)

H1 **Coastal Science Research**

P1

PRECISION IN PREDICTING EXTREME COASTAL EVENTS

This project aims to develop models for simulating extreme local wind waves and storm surge conditions, enhancing the understanding of the combined risks these events pose when they occur concurrently.

Development of probability distributions and extreme value analysis for storm surge levels, currents, wind waves and astronomic tides

PI: Dr Pavel Tkalich (NUS, TCOMS)

Models and methods developed through this research will provide Singapore's agencies, including the National Environment Agency and PUB, with advanced tools for long-term planning against coastal floods.

H1 **Coastal Science Research**

P2

UNRAVELLING UNCERTAINTIES IN COASTAL EXTREMES

This project aims to provide detailed insights into the factors influencing extreme coastal flooding events, enabling PUB to devise more effective risk mitigation strategies.

Hybrid physics-guided and data-driven attribution and uncertainty quantification of coastal extremes incorporating different sources of information

PI: Associate Professor Low Ying Min (NUS)

Importantly, research findings could offer insights into the impact of regional climate changes and global sea level rise on extreme coastal water events, supporting strategic planning and policy formulation.

TCOMS: Technology Centre for Offshore and Marine, Singapore

H2 **Monitoring, Prediction and Digitalisation of Coastal Environment**

P1

FORECASTING FLOODS, FAST

This project aims to develop advanced modelling tools that integrate machine learning with existing data to significantly enhance the accuracy of storm surge and wave forecasts along Singapore's coastlines.

Development of physics-informed data-driven storm surge and wave models

PI: Associate Professor Victor Wang (SIT)

Research findings will equip Singapore with the capability to predict storm surges with up to a five-day lead time — enhancing preparedness and response strategies when such conditions occur.

H2 **Monitoring, Prediction and Digitalisation of Coastal Environment**

P2

DATA-DRIVEN RAIN PREDICTION

Enhancing Singapore's convective rainfall prediction

PI: Professor Vladan Babovic (NUS)

This project explores the application of advanced technologies and methodologies to boost the speed and accuracy at which PUB predicts heavy rainfall.

From high-resolution rainfall re-analysis products to novel algorithms that integrate microwave links and CCTV footage to physics-informed machine-learning approaches, this research will help scientists understand how climate change and urbanisation affect convective rainfall patterns, supporting policy and planning to bolster flood response and management.

Coastal Protection and Flood Resilience Institute (CFI) Singapore

V1 **Innovative Engineering Solutions**

P1

BUILDING BETTER BARRIERS

Flexible seawall for coastal reservoir and coastal defence systems in Singapore

PI: Professor Chu Jian (NTU)

This project aims to advance coastal defence systems by developing an innovative, flexible seawall design. Compared with conventional bunds and breakwaters, the proposed systems are more cost-effective and offer adaptability and sustainability through intelligent engineering.

A floating box with an impervious, flexible curtain anchored to the seabed forms a highly adaptable seawall system. This reduces construction costs and offers flexibility for future redevelopment projects. Using less concrete and earth, it reduces ecological disturbance and is more environmentally friendly. Its height is also adjustable to ensure long-term adaptability.

V1 **Innovative Engineering Solutions**

P2

KEEPING THE RISING SEAS AT BAY

Modular solutions to retrofit existing coastal protection structures with impervious interlocking features which reduce seawater seepage

PI: Assistant Professor Chew Soon Hoe (NUS)

This project aims to develop modular, watertight units designed to enhance existing coastal protection structures — bolstering defences against the impacts of sea level rise.

A modular design allows for easy expansion and adaptation, ensuring long-term effectiveness and resiliency in line with future environmental changes. Research findings will also inform pilot field tests as well as engineering guidelines for the implementation of such systems.

V2 **Integrated Nature-based Solutions**

P1

PAINTING SINGAPORE'S SHORES GREEN-GREY

Shore protection with integrated nature-based solutions — Meta (SPINS-Meta)

PI: Associate Professor Peter Todd (NUS)

This project explores how combining natural ecosystems with engineering solutions can make coastal protection more sustainable. It also maps and identifies potential sites for hybrid 'green-grey' solutions.

It will help inspire innovative, cost-effective coastal protection measures that bake in ecological restoration — enhancing biodiversity and ecosystem services such as carbon sequestration. Findings will also inform relevant projects as well as national agendas, for instance, aligning with the Singapore Green Plan 2030 to mitigate the impacts of climate change and restore vital coastal ecosystems.

V2 **Integrated Nature-based Solutions**

P2

TAKING A LEAF OUT OF NATURE'S BOOK

Shore protection with integrated nature-based solutions — Hydro (SPINS-Hydro)

PI: Assistant Professor Gary Lei Jiarui (NUS)

This project develops and tests hybrid coastal protection strategies that blend traditional engineering structures with nature-inspired solutions.

Integrating mangroves and seagrasses into hybrid systems not only strengthens coastal defences but facilitates carbon sequestration and enhances biodiversity. This is a crucial facet of Singapore's response to rising sea levels, which helps to refine the city-state's coastal management practices, enabling resilient, highly adaptable infrastructure.

V2 Integrated Nature-based Solutions

P3

GREENING SINGAPORE'S GREY SHORES THROUGH NATURE-BASED SOLUTIONS

Shore protection with integrated nature-based solutions — Eco (SPINS-Eco)

PI: Associate Professor Peter Todd (NUS)

This project seeks to optimise the growth and survival of coastal species within hybrid defence systems.

Establishing the optimal biophysical conditions of key coastal species, such as mangroves, seagrasses, corals and macroalgae, could help them thrive within hybrid coastal protection systems. Insights and technologies stemming from this research could also be transferred to other agencies, enhancing coastal protection measures across Singapore and other regions facing rising sea levels.

EDUCATION & TRAINING

Educational programmes offered by CFI Singapore's partners include:

- Bachelor of Engineering (Civil) at NUS
- Bachelor of Engineering (Civil) with specialisation in Coastal Protection at NTU
- Bachelor of Engineering (Environmental) with specialisation in Coastal Protection at NTU
- Master of Science (Civil Engineering) with specialisation in Sustainable Climate Resilience at NUS
- Graduate Certificate in Coastal Protection and Flood Management at NUS
- Graduate Certificate in Digital Water at NUS

NUS and the Delft University of Technology have partnered to introduce a global exchange programme for those pursuing the Master of Science programme at NUS.

PARTNERSHIPS

CFI Singapore is working with identified partners on:

- Joint applied research projects to promote technology translation
- Visits by staff and students for discussion and participation in joint R&D activities, seminars and conferences
- Exchange of knowledge and other materials of mutual interest

FACILITIES

Key facilities that support CFI Singapore's research and industry initiatives:

NUS

Hydraulic Engineering Lab

Structural Engineering Lab

Geotechnical Engineering Lab

Transportation Engineering Lab

Digital Urban Infrastructural Lab

3D Printing Lab

NTU

Hydraulic Engineering Lab

Structural Engineering Lab

Geotechnical Engineering Lab

National level

Ocean Basin at TCOMS

Offshore/marine research facility at St. John's Island National Marine Laboratory

CFI SINGAPORE'S MANAGEMENT TEAM

Professor Adrian Law
Excutive Director and Director (Strategy, Partnerships & Technology Translation)

Professor Koh Chan Ghee
Director (Research)

Associate Professor Raymond Ong
Director (Operations)

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NUS National University of Singapore | Coastal Protection and Flood Resilience Institute Singapore College of Design and Engineering CFI SINGAPORE

Precision in Predicting Extreme Coastal Events

Development of probability distributions and extreme value analysis for storm surge levels, currents, wind waves and astronomic tides

PI: Dr Pavel Tkalich
National University of Singapore, College of Design and Engineering, Tropical Marine Science Institute and Technology Centre for Offshore and Marine, Singapore

What is this about?

This project aims to develop models for simulating extreme local wind waves and storm surge conditions, enhancing the understanding of the combined risks these events pose when they occur concurrently.

What is the goal?

- Analyse historical coastal phenomena to understand the extremes that compromise Singapore's resilience.
- Develop high-resolution storm surge and tide models (Delft3D-FM), and wind-wave models (WW3), using downscaled atmospheric forces from the Centre for Climate Research Singapore (CCRS).
- Provide projections for storm surges, tides and wind wave variability and extremes.
- Develop tools for calculating probability distribution functions and return periods (RPs) to support coastal flood risk assessments.
- Generate high-resolution scenarios of regional weather-climate extremes to inform strategic planning.

How is this done?

- Develop and deploy a 10-metre resolution flexible mesh model for storm surge and tide, as well as a wind-wave spectral model.
- Apply advanced statistical methods to establish RPs from 1 year to 10,000 years.
- Model non-linear phenomena near coastal protection systems.
- Optimise the WRF model to sub-kilometre resolutions for detailed studies of local atmospheric extremes.

Why does this matter?

- Models and methods developed will help Singapore's agencies, including the National Environment Agency and PUB, Singapore's National Water Agency, with long-term planning against coastal floods.
- Implementing high-resolution storm-surge, wind-wave and 3D hydrodynamic models will establish new benchmarks and expand local capabilities.
- Research output will remain relevant and can be continuously adapted and integrated with future IPCC assessments.

Unravelling Uncertainties in Coastal Extremes

Hybrid physics-guided and data-driven attribution and uncertainty quantification of coastal extremes incorporating different sources of information

PI: Associate Professor Low Ying Min
National University of Singapore, Department of Civil and Environmental Engineering, College of Design and Engineering

What is this about?

This project aims to provide detailed insights into the factors influencing extreme coastal flooding events, enabling PUB, Singapore's National Water Agency, to devise more effective risk mitigation strategies.

What is the goal?

- Develop a hybrid approach that merges diverse data sources with physics-guided attribution to analyse coastal extremes.
- Predict joint probabilities of extreme events and quantify the uncertainties of these predictions using confidence intervals.
- Create stochastic climate emulators to generate extensive ensembles of scenarios reflecting different potential climate futures.

How is this done?

- Employ COAWST modelling to process both hindcast and forecast data, producing wave and wind parameters, currents and storm patterns as outputs.
- Apply a Bayesian network to variables, processes and uncertainty sources to generate a joint distribution model of coastal extremes.

Why does this matter?

- This generates reliable statistical estimates for extreme sea levels and wave conditions with projections to 10,000-year return periods.
- Scientifically quantify uncertainties to provide more precise forecasts of potential extreme events, supporting the development of more effective mitigation strategies.
- Offer novel insights into the impact of regional climate changes and global sea level rise on extreme coastal water events, supporting strategic planning and policy formulation.

Forecasting Floods, *Fast*

Development of physics-informed data-driven storm surge and wave models

PI: Associate Professor Victor Wang
Singapore Institute of Technology, Engineering Cluster

What is this about?

This project aims to develop advanced modelling tools that integrate machine learning (ML) with existing data to significantly enhance the accuracy of storm surge and wave forecasts along Singapore's coastlines.

What is the goal?

- Build an advanced ML-based model that accurately and efficiently predicts storm surges along Singapore's coastlines.

How is this done?

- Analyse weather data likely to influence storm surges.
- Perform detailed feature design and engineering to identify predictors of storm surge occurrences.
- Select and deploy the most suitable ML model that balances prediction speed with accuracy.
- Test the model rigorously against a range of simulated and historical storm surge and weather data to ensure its reliability and accuracy.

Why does this matter?

- Equips Singapore with the capability to predict storm surges with up to a five-day lead time — enhancing preparedness and response strategies.
- Enables the formation of a network that utilises real-time local and global weather data to deliver quick and accurate predictions of storm surge heights.

Project H2-P2 — Monitoring, Prediction and Digitalisation of Coastal Environment

cde.nus.edu.sg/cfisg/

Data-Driven Rain Prediction

Enhancements of Singapore's convective rainfall prediction

PI: Professor Vladan Babovic
National University of Singapore,
Department of Civil and Environmental Engineering,
College of Design and Engineering

What is this about?

This project explores the application of advanced technologies and methodologies to boost the speed and accuracy at which PUB, Singapore's National Water Agency, predicts heavy rainfall.

What is the goal?

- Advance knowledge in dynamic and thermodynamic processes that influence the intensity of extreme convective storms in urban settings.
- Boost computational capabilities to support high-resolution, convection-permitting simulations of weather patterns that support inland flood modelling.
- Leverage machine learning (ML) and weather generators to improve real-time forecasting of convective storms and rainfall extremes.

How is this done?

- Combine existing rainfall monitoring networks to create a comprehensive re-analysis product and deploy high-resolution systems to assess the spatial-temporal variability of precipitation.
- Utilise microwave links and CCTV cameras for real-time rainfall mapping.
- Employ convection-permitting climate models to explore the impacts of climate change and urbanisation on rainfall extremes.
- Implement ML and stochastic weather generators for both short- and long-term rainfall forecasting.

Why does this matter?

- Provides Singapore with high-resolution rainfall re-analysis products, merging all available rainfall data for better accuracy and detail.
- Enables the development of algorithms that incorporate microwave links and CCTV footage into near real-time gridded rainfall products.
- Generates insights into how climate change and urbanisation affect convective rainfall patterns — supporting policy and planning.
- Refines hydrological models using physics-informed ML approaches for a better representation of hyperlocal convective rainfalls — bolstering flood response and management.

Building Better Barriers

Flexible seawall for coastal reservoir and coastal defence systems in Singapore

PI: Professor Chu Jian
Nanyang Technological University,
School of Civil and Environmental Engineering

What is this about?

This project aims to advance coastal defence systems in Singapore by developing an innovative, flexible seawall design. Comparing with conventional bunds and breakwaters, the proposed systems are more cost-effective and offer adaptability and sustainability at the same time through intelligent engineering.

What is the goal?

- Develop a new type of flexible seawall that integrates with coastal reservoirs to enhance Singapore's coastal defence infrastructure.

How is this done?

- The design involves a floating box with an impervious, flexible curtain anchored to the seabed, providing the basis for a highly adaptable seawall system.
- The seawall's height can also be adjusted, which enables it to be relocated as needed to respond to changing environmental conditions and urban developmental needs.

Why does this matter?

- This innovative design reduces construction costs and offers flexibility for future redevelopment projects.
- Minimises the use of traditional construction materials, such as concrete and earth, making the seawall more environmentally friendly while reducing ecological disturbance.
- Incorporates nature-based design elements that promote marine ecosystem conservation, aligning with environmental protection goals.
- Adjustments in seawall height ensures long-term adaptability.

Keeping the Rising Seas at Bay

Modular solutions to retrofit existing coastal protection structures with impervious interlocking features which reduce seawater seepage

PI: Assistant Professor Chew Soon Hoe
National University of Singapore, Department of Civil and Environmental Engineering, College of Design and Engineering

What is this about?

This project aims to develop modular, watertight units designed to enhance existing coastal protection structures — bolstering defences against the impacts of sea level rise.

What is the goal?

- Create modular units with impervious, interlocking features for retrofitting existing coastal defences to reduce seawater seepage.
- Units are also to be stackable and laterally expandable, accommodating progressive sea level rise and ensuring flexible adaptation to climate change.

How is this done?

- Comprehensive literature review and physical surveys of existing and new types of seawall and dyke constructions, both locally and internationally.
- Assess the latest coastal protection products and technologies, including interlocking armour blocks (X-BlocPlus) and wall facing systems (Humengi and BetaFlor block).
- Material testing and numerical modelling of a stackable, impervious system to assess stability and seepage under various sea level scenarios.
- Conduct geotechnical centrifugal modelling to validate the suitability as well as define the key design parameters of the system under realistic stress conditions.

Why does this matter?

- Stronger coaster defences that are more resilient to the challenges of rising sea levels.
- Modular design allows for easy expansion and adaptation, ensuring long-term effectiveness in line with future environmental changes.
- Findings will inform pilot field tests as well as engineering guidelines for the implementation of such systems.

Painting Singapore's Shores Green-Grey

Shore protection with integrated nature-based solutions — Meta (SPINS-Meta)

Associate Professor Peter Todd
National University of Singapore, Department of Biological Sciences, College of Humanities and Sciences

What is this about?

This project explores how combining natural ecosystems with engineering solutions can make coastal protection more sustainable. Potential sites for hybrid 'green-grey' solutions are also identified.

What is the goal?

- Develop a systematic understanding of hybrid coastal protection solutions implemented worldwide.
- Identify optimal combinations of 'green' (such as mangroves, corals and seagrasses) and 'grey' (such as seawalls and breakwaters) elements that fit Singapore's unique constraints.
- Pinpoint potential sites for implementing hybrid 'green-grey' solutions to maximise coastal protection and ecosystem benefits.

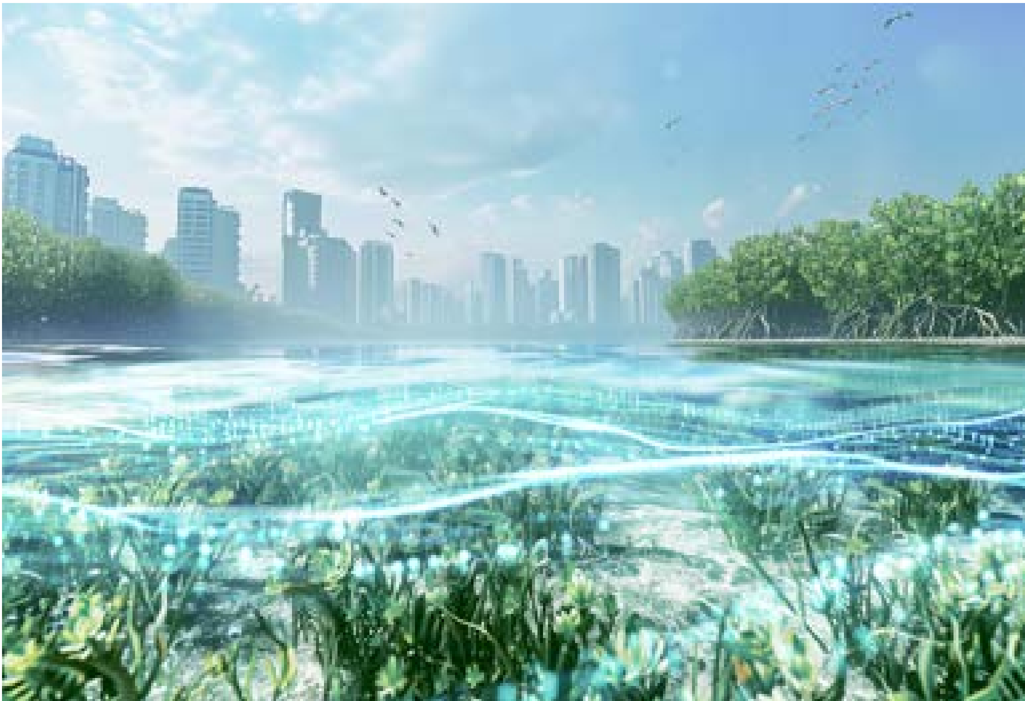
How is this done?

- Conduct an exhaustive review across multiple databases to gather data on existing hybrid solutions and their efficacy.
- Model and map coastal species and environmental conditions using high-resolution data, and apply ecological niche models to determine the best species-structure combination for Singapore.
- Harness satellite imagery and drone data to identify existing coastal protection structures and suitable sites for the integration of hybrid 'green-grey' systems.

Why does this matter?

- Inspires innovative, cost-effective coastal protection measures that bake in ecological restoration — enhancing biodiversity and ecosystem services such as carbon sequestration.
- Enables hybrid solutions in Singapore that are more sustainable and effective in the long run by incorporating natural elements.
- Findings will inform relevant projects as well as national agendas, for instance, aligning with the Singapore Green Plan 2030 to mitigate the impacts of climate change and restore vital coastal ecosystems.

Taking a Leaf Out of Nature's Book



Shore protection with integrated nature-based solutions — Hydro (SPINS-Hydro)

Assistant Professor Gary Lei Jiarui
National University of Singapore, Department of Civil and Environmental Engineering, College of Design and Engineering

What is this about?

This project develops and tests hybrid coastal protection strategies that blend traditional engineering structures with nature-inspired solutions.

What is the goal?

- Examine the mechanical performance of hybrid solutions under various flow conditions.
- Assess how nature-based solutions respond to the effects of climate change.
- Develop physical models to quantify the wave attenuation properties of hybrid structures.
- Formulate engineering guidelines for the standardisation of hybrid solutions.

How is this done?

- Controlled physical tests on model-scale hybrid solutions, measuring forces with load cells, and observing the response of nature-based elements using instruments such as high-speed cameras, acoustic doppler velocimeters and wave gauges.
- Transition successful laboratory experiments to field locations to evaluate the effectiveness of hybrid solutions under real-world conditions.

Why does this matter?

- A crucial facet of Singapore's strategic response to rising sea levels, providing robust coastal protection while integrating ecological benefits.
- The inclusion of mangroves and seagrasses not only strengthens coastal defences but facilitates carbon sequestration and enhances biodiversity.
- Outcomes will help refine Singapore's coastal management practices — leading to resilient, highly adaptable infrastructure.

Greening Singapore's Grey Shores Through Nature-Based Solutions

Shore protection with integrated nature-based solutions — Eco (SPINS-Eco)

Associate Professor Peter Todd
National University of Singapore, Department of Biological Sciences, College of Humanities and Sciences

What is this about?

This project seeks to optimise the growth and survival of coastal species within hybrid defence systems.

What is the goal?

- Establish the optimal growth conditions of key coastal species such as mangroves, seagrasses, corals and macroalgae.
- Develop strategies to improve the survivability of coastal species within hybrid shorelines, including under varying climates.
- Design and test hybrid structures that incorporate natural elements to enhance coastal protection.

How is this done?

- Multi-site field sampling and laboratory experiments to ascertain the biophysical requirements of coastal species, which can then be used to improve their growth conditions.
- Substrate modification and protective design to enhance the survival of saplings in natural settings.
- Use 3D design and printing to create topographically complex structures that support the growth of corals and macroalgae, as well as assessing their wave attenuation capabilities.
- Simulate how certain species respond to various climate change scenarios.

Why does this matter?

- Outcomes will contribute to Singapore's national coastal protection agenda while supporting its climate mitigation efforts.
- Insights obtained and technologies developed can be shared with partner agencies and the private sector alike, enhancing coastal protection measures across Singapore and potentially other regions facing similar challenges in rising sea levels.

Strengthening Coastal Models for Climate Adaptation

Model development and quantifications of coupled near-shore processes impacted by climate change

Assistant Professor Pearl Li
National University of Singapore,
Department of Civil and Environmental Engineering,
College of Design and Engineering

What is this about?

This project aims to develop advanced models to accurately simulate coastal processes in Singapore's distinct environment, characterised by extensive urbanisation, land scarcity, and low-lying areas. It also aims to quantify how these processes interact with and influence the coastline over time.

What is the goal?

- Enhance modelling capabilities for the hydrodynamics of coupled near-shore surface processes, including wind-waves, current and ship wakes, along Singapore's coast, as well as the underlying morphological sediment transport processes.
- Enable reliable, physics-based predictions of how climate-induced changes influence local coastal dynamics, such as waves, currents and sediment erosion.
- Enhance and calibrate large-scale, long-term predictions using results from detailed computational fluid dynamics (CFD) simulations.

How is this done?

- Develop advanced CFD models to simulate complex coupled near-shore processes.
- Integrate CFD models with phase-resolving potential-flow based models for efficient and accurate solutions.
- Conduct experiments in the NUS Hydraulic Lab and TCOMS large-scale ocean basin to validate and refine the numerical models.

Why does this matter?

- This project addresses concerns about how climate change will influence and amplify local coastal processes, including waves, current and erosion.
- The modelling and analysis tools developed will assist the design and planning of sustainable coastal infrastructure by accurately estimating the impact of coastal environments on structures and, conversely, the impact of coastal structures (and human interventions) on coastal dynamics.
- The results and insights gained are crucial for implementing coastal protection measures that enhance climate resilience and safeguard communities in Singapore's coastal areas.

Enhancing Sediment Monitoring with Smart Technology

Enhancements in the predictions of sediment transport around Singapore coastal waters

Professor Adrian Law
National University of Singapore,
Department of Civil and Environmental Engineering,
College of Design and Engineering

What is this about?

This project aims to enhance the understanding of sediment transport and develop cost-effective remote sensing techniques for long-term monitoring of suspended sediment distributions in Singapore's coastal waters.

What is the goal?

- Develop a coupled satellite-UAV remote sensing approach to monitor suspended sediment in Singapore's coastal waters.
- Investigate the sediment characteristics and determine the incipient shear stress of bed sediments in the region.
- Enhance the assessment of sediment transport around Singapore's coastal waters under various climate change scenarios.

How is this done?

- Use AI-driven image analytics algorithms to eliminate obstructions and enhance the spatial resolution of satellite remote sensing imagery by fusing it with high-resolution UAV imagery.
- Perform field measurements and laboratory experiments to comprehensively investigate the critical shear stress and develop generalised Shield's curves for bed sediment mixtures in Singapore's coastal environment.
- Employ the DELFT3D numerical model, along with enhanced data, to assess sediment transport in Singapore's coastal waters, especially during extreme storm surge events.

Why does this matter?

- This project will attain long-term monitoring of suspended sediment by combining advanced satellite and UAV remote sensing.
- Research outcomes will contribute to a deeper understanding of Singapore's coastal dynamics and improve the ability to assess the performance of shore protection schemes with greater confidence.
- A better understanding of mixed sediment transport behaviour will provide a strong foundation for testing and verifying numerical models, thereby enhancing the assessment of sediment transport influence zones and local coastal erosion.

Managing Urban Flood Risks

Network of experimental catchments for understanding runoff formation and flood risk

Associate Professor Simone Fatichi
National University of Singapore,
Department of Civil and Environmental Engineering,
College of Design and Engineering

What is this about?

The project aims to enhance the understanding of runoff generation processes in Singapore and enable more precise flood risk assessments in a changing climate.

What is the goal?

- Establish a network of experimental catchments to study runoff formation in Singapore.
- Integrate observations with advanced physics-based hydrological models and machine-learning models to deepen the understanding of runoff generation processes and improve the accuracy of flood risk assessments.
- Evaluate the effectiveness of current drainage infrastructure in the context of a changing climate and increasing urbanisation through scenario analyses.

How is this done?

- Five experimental catchments will be equipped with state-of-the-art sensors for runoff monitoring and flood assessment across different parts of Singapore.
- Continuous measurements of meteorological and hydrological variables will be combined with intensive field campaigns to characterise the physical and hydraulic properties of soil.
- Hybrid physics-based and data-driven (machine learning) hydrological models will be developed and used for rainfall-runoff simulations and flood risk analysis.

Why does this matter?

- This project will develop better hydrological models to predict floods and test various mitigation strategies.
- Understanding how rainfall transforms into runoff and how water flows in tropical urbanised catchments can lead to the design of effective drainage systems and flood-retention solutions.
- Assessing inland flood risk in a changing climate will provide critical information to support climate-resilient urban planning and infrastructure development decisions.

Smart Floating Systems for Coastal Protection

Smart and multifunctional floating structures for coastal protection and flood control

Associate Professor Qian Xudong
National University of Singapore,
Department of Civil and Environmental Engineering,
College of Design and Engineering

What is this about?

This project aims to develop coastal protection solutions at two targeted locations off Singapore's coast using both anchored and floating structures. These multifunctional breakwaters are designed to reduce wave impact and coastal erosion while integrating green energy harvesting facilities, such as tidal, wave and solar energy.

What is the goal?

- Integrate floating breakwaters into an anchored system that allows incremental builds to protect coastlines against extreme weather events caused by climate change.
- Develop modular, multifunctional anchored and floating structures for two targeted coastal locations in Singapore, co-located with green energy harvesting facilities.
- Propose labour-light and decarbonised construction technologies for coastal infrastructures, including intermodular connectors, IoT sensor nodes and modelling techniques.

How is this done?

- Design and assess anchored and floating breakwaters built using a modular construction framework and plug-and-play assembly, integrated with marine energy co-harvesting devices.
- Develop engineering guidelines and green construction technologies that are less labour-intensive.

Why does this matter?

- This project provides targeted solutions for offshore areas in Singapore that currently lack effective coastal protection measures.
- Multifunctional breakwaters can adapt to sea-level rise and are cost-effective for deep waters.
- Floating structures provide sheltered spaces; both anchored and floating structures offer flexibility in design, placement and reconfiguration.
- Co-location with marine energy devices provides green energy to areas not connected to the grid.

Cementing Sustainable Solutions

Eco-cement enhanced methods for beach erosion control and beach land restoration through soil accumulation

Professor Chu Jian
Nanyang Technological University,
School of Civil and Environmental Engineering

What is this about?

This project aims to develop a cost-effective and eco-friendly method for coastal protection and recovery of land lost due to sea-level rise by elevating the beach profile through soil accumulation.

What is the goal?

- Establish a method of using eco-cement and jute fabric to form barriers.
- Conduct a preliminary study for future living lab field tests to convert the proposed solution into a viable construction method.
- Evaluate the design's performance through model tests and use monitoring data to calibrate and verify the software used for design and analysis.
- Develop guidelines for design, construction, material selection and specifications for practical application of the developed method.

How is this done?

- Conduct laboratory tests to develop eco-cement and jute materials, and determine the optimal binder-to-soil ratio for eco-cement.
- Use a specially designed beach erosion tank with a wave generator to test methods for preventing beach erosion and retaining soil to gradually elevate the beach profile.

Why does this matter?

- Soil-filled jute tubes or bags can form barriers to prevent coastal erosion and accumulate sediments, helping to restore land inundated by seawater.
- This method not only prevents erosion and preserves biodiversity but also minimises disturbances to marine ecosystems.
- This research supports Singapore's Green Plan 2030 and the Zero Waste Policy with a sustainable, eco-friendly solution.

Harmonising Engineering Solutions with Nature

An Integrated Coastal Ecosystem Model (ICEM) to assess the environmental impacts of anthropogenic activities and climate change on hybrid solutions

Professor Karina Gin
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What is this about?

This project aims to evaluate the effectiveness of hybrid coastal protection strategies by balancing natural and artificial elements using the Integrated Coastal Ecosystem Model (ICEM). The focus is on enhancing the sustainability and functionality of coastal protection systems amidst the challenges posed by climate change and human activities.

What is the goal?

- Study ecological interactions within the coastal ecosystem and develop an Integrated Coastal Ecosystem Model (ICEM).
- Assess the impacts of climate change and human activities on hybrid solutions under different scenarios.
- Develop evidence-based guidelines for the implementation of nature-based solutions.

How is this done?

- Conduct laboratory and field experiments to study the interactions between seagrasses, mangroves, algae, environmental factors and man-made structures.
- Utilise data collected to develop the Integrated Coastal Ecosystem Model (ICEM), which integrates hydrodynamic, water quality and ecological models.
- Simulate complex coastal interactions under various stressors to enhance the understanding and management of coastal protection systems.

Why does this matter?

- The research findings and model developed will help Singapore in developing and evaluating hybrid strategies to enhance the nation's coastal resilience against rising sea levels and climate change.
- By optimising the balance between natural and artificial elements, this project supports Singapore's efforts in effective climate adaptation and long-term coastal protection.

Enhancing Seawalls for Coastal Resilience

Promoting hybrid solution resilience by optimising hydrodynamical and structural influences on coral larval attachment to reefs and sediment clustering amid seagrass

Dr Ronald Chan
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What is this about?

This project aims to enhance the effectiveness and sustainability of coral-infused hybrid coastal protection systems. This research will provide insights to optimise these structures to mitigate the impacts of increasing wave action and sediment displacement on coral larval settlement.

What is the goal?

- Evaluate the effectiveness of artificial reefs and seagrass arrays in dissipating energy and releasing sediment from incoming waves and currents.
- Predict sediment clustering and the forces acting on suspended and settling coral larvae as functions of ambient flow conditions and surrounding structures.
- Develop best practices for selecting, designing and placing structures to minimise obstruction and detachment of coral larvae.

How is this done?

- Investigate how artificial reef models dissipate wave and current energy using velocity sensors and wave gauges in wave basin tests and numerical simulations.
- Evaluate how seagrass arrays deform and release sediments under incoming flows through seawater flume experiments and numerical simulations.
- Compute how fluid–structure interactions mitigate turbulence and affect the movement and settling of coral larvae at both larval and structural scales.

Why does this matter?

- Seawalls are a core component of Singapore's strategy to combat rising sea levels and stronger storm surges, and their surfaces have been observed to promote coral growth.
- The sustainability of these hybrid coastal protection solutions depends on promoting and ensuring the survival of coral generations.
- The models developed can help identify factors that hinder coral larval settlement and growth, and suggest methods to optimise the configuration and design of these structures.

Taking Hybrid Solutions to a New Level

Maximising the beneficial environmental effects of tropical hybrid shorelines (MaxBETH)

Associate Professor Peter Todd
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What is this about?

With the increasing demand for coastal protection, this project aims to evaluate the effectiveness of hybrid shorelines that combine vegetation with hard structures, particularly under the challenges posed by climate change and human activities.

What is the goal?

- Compare both traditional coastal engineering structures ('grey solutions') and natural coastal ecosystems ('green solutions') to quantify the additional benefits that integrated solutions can provide.
- Assess the challenges and benefits of scaling up hybrid shoreline solutions.
- Identify the impacts of hybrid shorelines on biophysical processes.

How is this done?

- Explore the potential benefits of incorporating habitat complexity at scales ranging from millimetres to hundreds of metres, based on field data and simulations.
- Conduct simulation experiments with artificial vegetation in laboratory and field settings to obtain comprehensive data on flow dynamics, sediment resuspension/retention, and gas transfer around hybrid solutions.
- Undertake a pan-island sampling regime to measure ecosystem health, focusing on metrics such as the community-level biomass production rate.

Why does this matter?

- The research findings will be useful in developing and implementing alternative coastal protection strategies to address the long-term challenges of sea level rise.
- Integrating nature-based solutions has the potential to mitigate climate change. For example, mangrove trees and seagrasses can sequester carbon as their biomass increases.
- This project will generate both fundamental and applied knowledge, offering insights into upscaling eco-engineering designs, the benefits of hybrid solutions and the creation of ecological models and decision-making tools.