



# INFRASTRUCTURE ENGINEERING GRADUATE RESEARCH CONFERENCE (IEGRC) 2022

02 NOV 2022

Organised by  
Department of Infrastructure Engineering  
The University of Melbourne

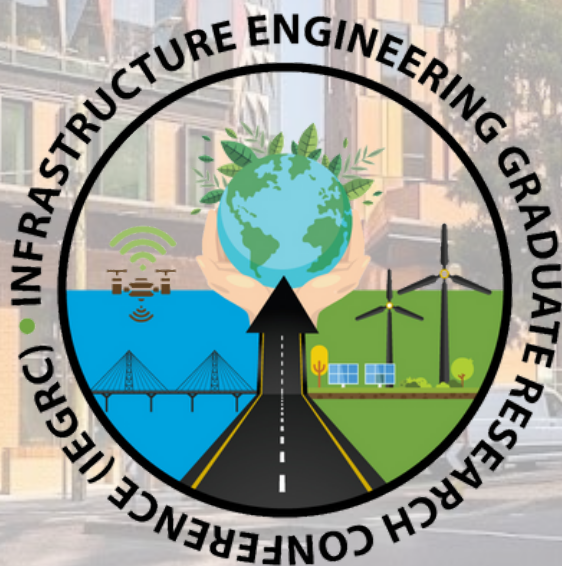


GRADUATES  
INFRASTRUCTURE  
ENGINEERING  
SOCIETY

# THE PROCEEDINGS OF THE Infrastructure Engineering Graduate Research Conference (IEGRC) 2022

2nd November 2022

Melbourne Connect Superfloor





# FOREWORD

Welcome to the 2022 Infrastructure Engineering Graduate Research Conference. Today is a great opportunity for all you, as graduate research students, to showcase your research and, importantly, to hear about the work of your colleagues.

Hearing from others is an opportunity to get new ideas by seeing what your colleagues have been working on. It is sometimes said that research is not done until it is published, or perhaps communicated, and oral presentation and written communication skills are absolutely critical, both in research and in industry. Being able to pitch your work so it can be understood by the audience and so that the audience understands why it is important will set you in good stead for your future. Listening actively is also an important skill.

Today is all about doing that and if past conferences are a good guide, I am sure we will see many fantastic presentations of great research. I hope you all enjoy the day and come away with new ideas. Finally, I would like to thank all those involved in making the conference a success.

**Professor Andrew Western**  
Head of Department  
Department of Infrastructure Engineering  
The University of Melbourne



# KEYNOTE SPEAKERS



## **Dr Asal Bidarmaghz**

**Senior Lecturer**

**School of Civil and Environmental Engineering, UNSW Sydney**

**Dr Asal Bidarmaghz** is a Senior Lecturer in Geotechnical Engineering at the School of Civil and Environmental Engineering, UNSW. Asal was working as a Research Associate at the Engineering Department, Cambridge University (2017 – 2019). She has also worked as a Post-Doctoral Research Fellow at the Department of Infrastructure Engineering, the University of Melbourne (2015 – 2017). Asal received her PhD in Civil Engineering (Geothermal Technologies) from the University of Melbourne in 2015. Asal specialises in geo-energy systems, and hydro-thermo-mechanical characteristics of urban subsurface and underground structures synergistically with above/underground built environment.

Her research concerns large-scale simulation of urban underground heat island and the quantification of its consequent geotechnical, environmental and hydrological impacts with specific emphasis on sustainable and resilient utilization of underground structures and geo-energy resources. Asal's research has led to new urban-scale methods and tools for predicting the ground temperature and groundwater distributions at high resolutions in the presence of underground heat sources and sinks.

## **Dr Eleanor Gee**

**Senior Coastal Scientist**

**Waikato Regional Council**



**Dr Eleanor Gee** is a Senior Coastal Scientist at Waikato Regional Council in New Zealand. Prior to that, she worked as a hydroecologist at National Institute of Water and Atmospheric Research in New Zealand (2016 – 2022) and a hydrologist at Bureau of Meteorology in Melbourne, Australia (2015 – 2016). Eleanor received her PhD from the University of Melbourne, where she also worked as a Research Fellow in Hydro-ecology before (2014 – 2015).

Eleanor has the enthusiasm in contributing to the growing need for an understanding of the interactions between physical and biological processes in aquatic systems, and in contributing to policy making around water resources. Eleanor has intensive experience in hydrology modelling and field data collection, as well as programming using various computational languages and policy and management advice.



# PANEL DISCUSSION



## Dr Debaditya Acharya

Lecturer in Geospatial Science, RMIT University

**Dr Debaditya Acharya** is a Lecturer in Geospatial Science at RMIT University, and teaches photogrammetry and remote sensing, and his research interests are computer vision, machine learning, and 3D building modelling. Debaditya completed his Doctor of Philosophy from the University of Melbourne, working on visual indoor localisation using 3D building models. Subsequently, he worked in the industry with CSIRO as an Early Research Career Postdoctoral Fellow, where his work contributed to the Future Science Platforms of Machine Learning & Artificial Intelligence working in the area of anomaly detection using location information and visual data.



## Dr Maria Panagiotidou

Sustainable Buildings Engineer, Arup

**Dr Maria Panagiotidou** is an ESD Engineer at Arup. She obtained her Doctor of Philosophy from the University of Melbourne in 2020, with her research focusing on building energy simulation and optimisation, particularly for retrofits considering energy saving measures, HVAC, and renewable energy systems.



## Dr Azadeh Emami

Network Optimization Engineer, Department of Transport

**Dr Azadeh Emami** is a Network Optimization Engineer at the Department of Transport. She obtained her Doctor of Philosophy from the University of Melbourne. She has more than 5 years of strong experience in research activities, traffic modelling and prediction, control and simulation, traffic data analysis, traffic signal design and optimization.



## Ms Joyce Ferng

Associate Director, ANZ Modular Lead, AECOM

**Joyce Ferng** is an Associate Director at AECOM and currently leading the ANZ modular initiatives within the organisation. She has 20 years of international experience such as chartered structural engineer and has delivered structurally complex and challenging projects in Singapore, UK, and Australia. Joyce developed a passion for prefabrication construction and gained extensive modular construction and management experiences during her role as modular Senior Design Manager. She is a great prefabrication advocate and believes that systemisation technology is the future of our construction industry. Joyce is also currently involved in various modular research initiatives with the universities.



# PANEL DISCUSSION



## **Prof Mark Cassidy**

Dean of Faculty of Engineering and Information Technology,  
Professor of Civil Engineering, University of Melbourne

**Professor Mark Cassidy** is Dean of the Faculty of Engineering and Information Technology at the University of Melbourne. Mark graduated in Civil Engineering from the University of Queensland, and as a Rhodes Scholar, attained a doctorate in Engineering Science from the University of Oxford. Prior to his appointment in Melbourne, he was an Australian Research Council (ARC) Laureate Fellow, Director of the Centre for Offshore Foundation Systems (COFS), Deputy Director of the ARC Centre of Excellence for Geotechnical Science and Engineering (ARC CoE CGSE) and the Lloyd's Register Foundation Chair of Offshore Foundations at the University of Western Australia. Mark's research interests are in offshore geotechnics and engineering, predominantly in developing models for the analysis of oil and gas platforms, mobile drilling rigs, renewable wave and wind turbines, anchors, and pipelines. Mark is the 2015 Western Australian Scientist of the Year and is the 2007 recipient of the Malcolm McIntosh Prize for Physical Scientist of the Year, one of the Prime Minister's Prizes for Science. He is a three-time recipient of the Institution of Civil Engineers (ICE) David Hislop Award for the best paper on offshore engineering (2003, 2014 and 2017), as well as the 2012 recipient of the ICE's Geotechnical Research Medal for the best paper on geotechnical engineering. He is also an elected Fellow of the Australian Academy of Science (FAA), the Australian Academy of Technology and Engineering (FTSE) and of Engineers Australia (FIEAust).

## **Mr Mark Allan (Moderator)**

Director Greenline, City of Melbourne



Mark Allan is an architect and urban planner with a master's degree from the Melbourne Business School. With a career spanning 30 years in sustainable urban development and major urban renewal projects Mark has played key roles in planning for Federation Square, Melbourne Docklands, and the Queen Victoria Market Precinct Renewal. In his current role at the City of Melbourne he is Director Greenline a city shaping project set to transform the north bank of the Yarra River Birrarung. Mark has previously held senior roles in architectural practice and at Mirvac, VicUrban and the former Melbourne Docklands Authority. He has received numerous awards including the prestigious Australia Award for Urban Design. Mark is a Fellow of the Australian Institute of Architects and the Planning Institute of Australia and a PhD candidate at the University of Melbourne. He has chaired various industry advisory committees for the Property Council of Australia, the University of Melbourne, the Australian Sustainable Built Environment Council (ASBEC). Mark's research and practice interests include urban regeneration, the UN Sustainable Development Goals (SDGs) and the design of cities and sustainable precincts

# GIES COMMITTEE

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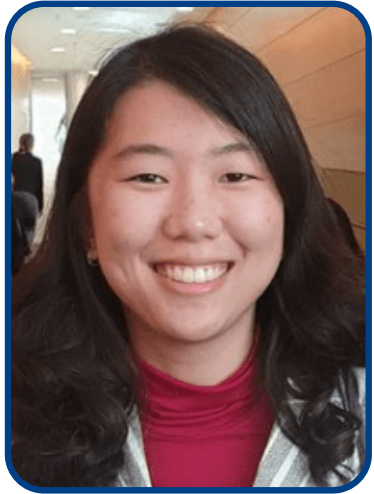
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**DEPARTMENT ADMINISTRATOR**  
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**DEPARTMENT ADMINISTRATOR**  
Rajes Moodley



# ACKNOWLEDGEMENTS

The organising committee of the **Infrastructure Engineering Postgraduate Conference 2022 (IEGRC 2022)** of the Department of Infrastructure Engineering are grateful to the following people of the Department of Infrastructure Engineering for kindly helping the committee by agreeing to be the judges of the Best Paper Submission, members of the Panel Discussion, Session Chairs and Moderator:

## **Panelists:**

Prof Mark Cassidy  
Dr Asal Bidarmaghz  
Dr Debaditya Acharya  
Dr Maria Panagiotidou  
Dr Azadeh Emami  
Ms Joyce Ferng

## **Session chairs:**

Dr Soheil Sabri  
Dr Margarita Saft  
Dr Anamitra Roy  
Dr Tu Le  
Dr Iman Roozbeh  
Dr Yifa Wang  
Dr Tharaka Gunawardena  
Dr Massoud Sofi  
Dr Khuong Bui  
Mr Tristan Graham

## **Moderator:**

Mr Mark Allan

# ABOUT THE PROCEEDINGS

Welcome to the proceedings of the Infrastructure Engineering Graduate Research Conference (IEGRC 2022) of the Department of Infrastructure Engineering.

This book summarises the abstracts of the presentations given across six sessions encapsulating the diversity of Infrastructure Engineering from presenters enrolled in the Doctor of Philosophy programs who are at various stages of candidature in the Department of Infrastructure Engineering at the University of Melbourne, Australia.

The summary of the Panel discussion held on “Engineering in a changing world”, which is the theme of IEGRC 2022 and the awards given out to students are also presented.



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THE UNIVERSITY OF  
MELBOURNE

# GEOMATICS



# A Performance Approach for Placemaking in Urban Renewal Projects to Support the SDGs



**Name:** Mark Allan  
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**Supervisor(s):** Prof Abbas Rajabifard, Prof Greg Foliente  
**Discipline:** Geomatics

## ABSTRACT

We exist at a time when over 50% of people live in cities and 50% can access the internet – half can't. Urban populations are under stress from the impacts of climate change, natural and human disasters, increasing global population and urban growth. In response to these challenges this research will critique the UN SDGs, other sustainable rating tools and review literature. The aim is to develop an integrated and systematic framework to support local governments and urban practitioners to utilise information and data analytics to better plan, design and deliver public space in cities and promote sustainable urban regeneration improve human health and wellbeing.

## INTRODUCTION

Cities globally are looking for new and efficient ways to use information and data, including spatial data and analytics. The aim is to improve decision making, make urban environments more sustainable, benchmark performance, build resilience, and improve the quality of life of urban dwellers. Engagement with communities on the design of public space is a critical component in the delivery of sustainable and high quality urban environments which impact overall societal wellbeing.

## METHODOLOGY

A mixed methods research approach will be used combining a Whole-of-life Performance-based Assessment with Design Thinking using quantitative and qualitative modelling and analytical methods. 'Top-Down, Bottom-Up' methods will be applied (refer Figure 1) combined with 'action learning' and 'action research' utilising 'state of practice' from government and industry with 'state of the art' from scientific research. A case study will investigate the Greenline urban renewal project on the north bank of Melbourne's Yarra River – Birrarung (refer Figure 2).

## DISCUSSION

The development of a performance-based framework and associated placemaking tools will add to knowledge with an eventual aim of creating more vibrant and people centric urban public spaces as part of sustainable urban revitalisation leading to improvements to urban quality of life, human health and wellbeing, and overall community resilience.

## FIGURE/DATA

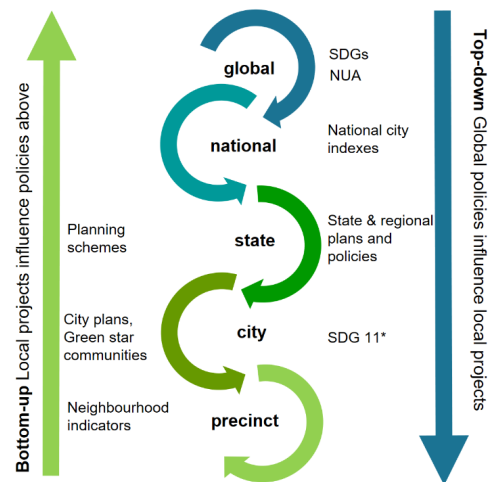


Image adapted from [www.povertyresearch](http://www.povertyresearch) 2020

Figure 1 Top-down – Bottom-up Methodology

## Meet your new Greenline Digital Twin which will enable us to...

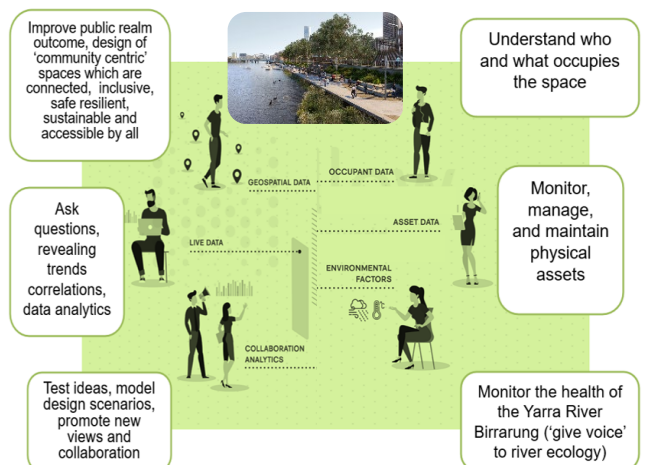


Figure 2 Greenline Case Study





**Name:** Reza Arabsheibani  
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**Supervisor(s):** A/prof Martin Tomko, Prof Stephan Winter  
**Discipline:** Geomatics

## ABSTRACT

For humans as for robots, what can be a more fundamental problem than getting from here to there. Many instruction sets can describe a route to a destination for an agent in an unknown indoor environment. and some of these are less ambiguous or erroneous than others. Error and ambiguity may impact the validity of route instructions. A valid route instruction must convey the agent to the desired destination. The output of this study will be a model that enables automatic route instruction validation. This model integrates spatial knowledge, logic, and natural language understanding using an executable text environment.

## INTRODUCTION

People need guidance to find a path in unvisited indoor spaces. A route instruction is valid for recipients if they can use provided information on decision points to choose an action that leads to the desired destination. Route instructions are provided to wayfinders without certainty that they can follow. The main research question of this study is how can we automatically validate route instructions for guiding wayfinders?

We hypothesise that the validity of route instructions for an agent is derivable from the actions it describes, in a way that instruction is valid if the following conditions hold:

- (1) in every state, the agent can follow the instructed action (unambiguously or via inference)
- (2) the actions should result in a path
- (3) After last action, the agent reaches the desired (intermediate) destination.

## DISCUSSION

We have looked at the state-of-the-art executable text environments and assessed them based on their expressiveness in modelling the real world and identified that current environments could represent real-world buildings only to some extent. For example, the hall definition is not straightforward in executable text environments, although we have implemented Chadstone Shopping mall in Inform7. This will be completed through the whole study.

We have implemented a method for conversion of geometric information of indoor spaces into Inform7 spaces. Besides, new action is defined for better user interaction between the agents and the environment. In the next steps rule-based agents and learning-based agents will be assessed for instruction following application that finally leads to validation.

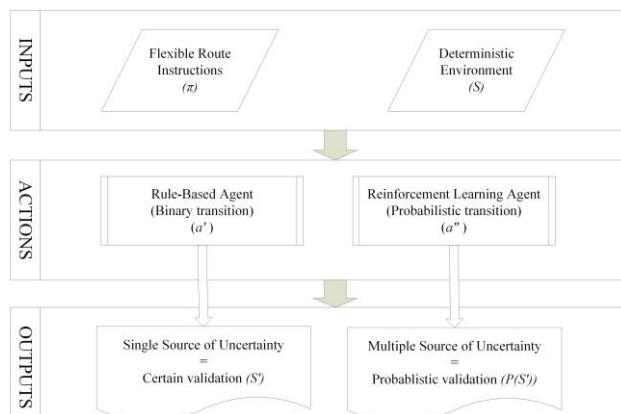
## METHODOLOGY

The structure of the proposed method includes modelling of real-world spaces in an executable text environment, translation of route instruction into actions, following actions, and assessing the navigation based on the length and proximity criteria. The flowchart demonstrates the schematic inputs, processes, and outputs of the proposed approach for the validation of route instructions.

The approach is decomposed into stages, each addressing a partial research question:

- How can we represent real environments computationally so that all aspects of the environment's relevance, the information requirements of the grammars, and agent capabilities are supported?
- How can we translate route instructions into agent actions?
- How can we validate route instruction deterministically?
- How to estimate the validity probabilistically?

## FIGURE/DATA



# Remote Sensing Based Bushfire Severity and Postfire Short-term Vegetation Recovery Assessment



**Name:** Saroj Kumar Sharma  
**Email:** [sarojkumars@student.unimelb.edu.au](mailto:sarojkumars@student.unimelb.edu.au)  
**Supervisor(s):** Dr Jagannath Aryal (primary), Prof Abbas Rajabifard  
**Discipline:** Geomatics

## ABSTRACT

In this study, we assessed bushfire severity and post-fire vegetation recovery by using Landsat images in Google Earth Engine (GEE) platform. As a case study, we considered the catastrophic 2009 Black Saturday Bushfires of Victoria. The trajectory of postfire vegetation recovery process was assessed by generating time series (2008-2020) of Normalised Difference Vegetation Index (NDVI). We examined relative importance of climatic and topographic predictors in recovery by using Random Forest model. We found that the burned areas regained NDVI of pre-fire year in five to six years, where rapid recovery was observed in the first three years. The recovery process was largely influenced by temperature (55%), followed by topography (26%), soil water volume (10%), solar radiation (5%), and precipitation (4%), respectively.

## INTRODUCTION

Understanding postfire vegetation recovery dynamics is important for successful restoration treatments. This requires a regular monitoring of fire induced environmental changes and understanding of the role of influencing drivers. However, fire severity, its impact on vegetation recovery and the role of potential drivers are not yet fully explored. Further, recent advancement in Earth Observation (EO) data and analytical platform, such as, Google Earth Engine (GEE) provides an unprecedented opportunities for reliable interpretation of EO imagery to address the problem. Hence, by utilising the capabilities of GEE, this research answered spatial variability and bushfire severity with a focus on following questions.

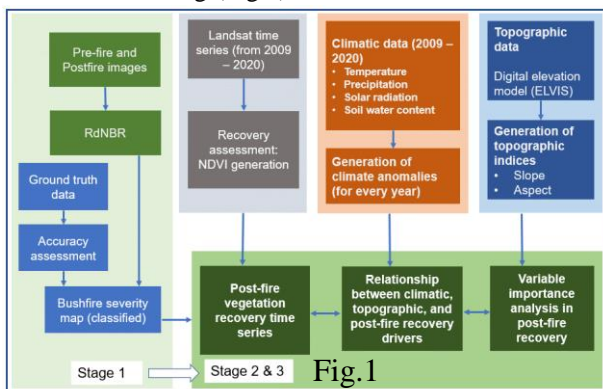
1. How is degree of burn severity affects post-fire vegetation recovery trajectory?
2. How climatic and topographic variables influence postfire recovery patterns?

## METHODOLOGY

**Study Area:** 2009 Black Saturday Bushfire, Victoria

**Data :** Landsat images (from 2008 to 2020), climate data (ERA-5 Land), topographical data (ELVIS DEM)

**Method:** Stage 1) Bushfire severity mapping and accuracy assessment. Stage 2) Time series analysis and recovery assessment. Stage 3) Variable importance analysis and statistical modelling (Fig.1).



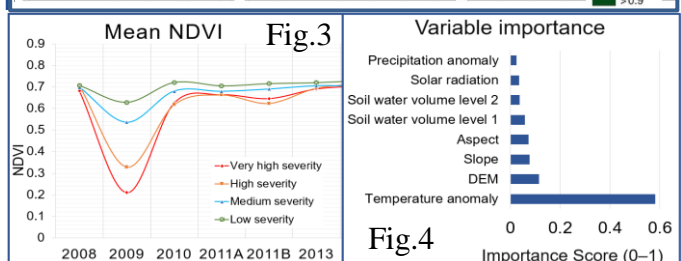
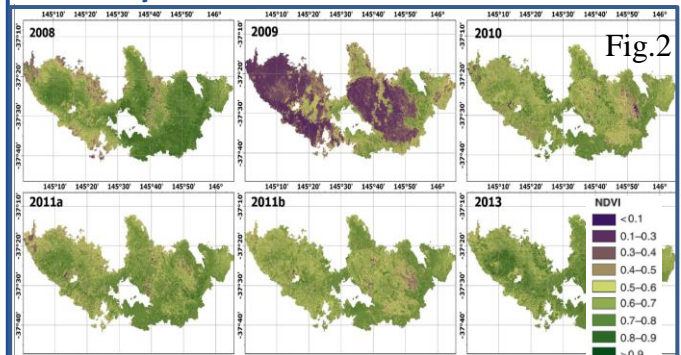
## DISCUSSION

- Computed NDVI time-series (Fig. 2) of before and after fire showed the area experienced rapid recovery of NDVI in subsequent three years, which was consistently improved and almost reached to that of prefire NDVI in five years.
- Bushfire severity and its spatial variability played a dominant role in governing potential vegetation recovery. In overall, the areas with less severe fires experienced quick recovery than the areas with high severe fires.

### Application to Practitioners

- Understanding vulnerable areas with poor postfire recovery potential helps land managers to prioritise recovery efforts.

## FIGURE/DATA





# Mapping the effects of disasters in informal urban growth patterns. The case of Mocoa, Colombia

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## ABSTRACT

The world has seen a significant increase in the number of people living in informal urban settlements. The people living in informal urban settlements are often the most at risk in disaster-prone cities as they usually settle in hazardous areas and are physically and socially vulnerable. They tend to be displaced again after a disaster, whether because they lost everything or the authorities relocated them. This research aims to map the effects of the 2017 disaster in Mocoa, Colombia, on the informal urban growth patterns. Mapping the public policies surrounding informal urban settlements leads to a discussion on how disaster recovery policies and informal urban growth are interweaved in the disaster process.

## INTRODUCTION

On the night of the 31st March 2017, after heavy rainfall, a series of landslides generated mudslides that came to town through two creeks. After a similar mudslide in 1962, a large conflict-displaced population informally settled in the recently affected area. Without proper planning from the local administration, they kept growing for five decades until the 2017 mudslides hit the city. They destroyed the informal settlement and 40% of the urban area.

## METHODOLOGY

Mapping the effects of this disaster on Mocoas' informal growth involved a multiyear land cover classification developed using a deep learning model. Furthermore, this research analyses the recovery policies around IUS before and after each disaster through comparative analysis methods.

- Collect multiyear aerial and satellite imagery datasets
- Collect recovery policies (before/after)
- Define the urban sprawl pattern of the IUS
- Compare its growth pattern (before/after)
- Compare growth pattern against recovery policies

## DISCUSSION

The Mocoa disaster of 2017 was key in the changes in recovery policies in Colombia. This disaster made the country realise there is no point in investing millions of dollars in recovery and reconstruction if it was not done resiliently. The National Office for Disaster Management of Colombia (UNGRD) has shifted towards a prevention culture from a recovery one. This means that there is now more attention towards legalising Informal Urban Settlements and, unfortunately, the relocation of those in hazardous areas again.

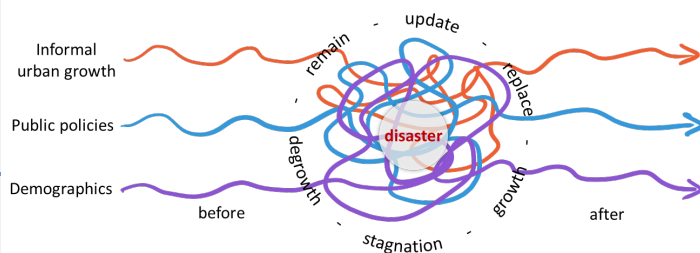
## FIGURE/DATA

Mocoa, COLOMBIA



Before the disaster  
(24th March 2017)

After the disaster  
(4th April 2017)



# Improving demolition waste management by developing a BIM-based sustainability assessment framework



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## ABSTRACT

The AEC industry has not yet been equipped with an approach to assess the sustainability performance of various demolition waste management scenarios, which is easily adaptable to the local context. A decision-aiding framework combining Life Cycle Sustainability Assessment (LCSA) and Multi-Criteria Decision Aiding (MCDA) methods with Building Information Modelling (BIM) is developed. The approach evaluates the performance of DWM alternatives according to eight sustainability indicators. Analytic Hierarchy Process (AHP) was adopted to weigh the indicators. The TOPSIS method was employed to rank the DWM scenarios. In this process, BIM acts as a data repository to empower the data exchange and visualization of the assessment results. Moreover, a building demolition project located at the Parkville campus of the University of Melbourne was selected as a case study to demonstrate the applicability of the proposed approach.

## INTRODUCTION

Sustainable development is not just about alleviating the environment impacts, it also involves manifold social, and economic factors. Furthermore, multiple stakeholders with different initiatives and knowledge background are involved in the construction project, which inevitably increases the uncertainty and divergence in the decision-making process. Thus, This research aims to propose a BIM-based decision-aiding approach integrating MCDA and LCSA methodologies for benchmarking the sustainability performance of different DWM scenarios to assist stakeholders in selecting the optimal DWM alternative.

## METHODOLOGY

- A modified Delphi method combining semi-structured interviews and questionnaires was adopted to identify and weigh the sustainability indicators for assessing the sustainability of DWM.
- Analytic Hierarchy Process (AHP) was employed to determine the weight of each indicator
- BIM was adopted the data repository for life cycle inventory analysis; Material quantities were obtained by BIM-based quantity takeoff and imported into the SIMAPRO with the custom Excel template
- TOPSIS method was used to rank the DWM alternative

## DISCUSSION

According to the expert panel feedback obtained from the second questionnaire, GWP is the most crucial sustainability indicator affecting the overall outcomes of DWM, yielding the highest normalized principal eigenvector (weight=32.03%). Consumption, with a relative weight of 16.08%, is also highly regarded by the expert group. Next, land use and acidification potential with eigenvector values of 13.52% and 12.1% ranked third and fourth, respectively. Lower in the hierarchy, no sustainability indicator has a respective weight above 10%; thus, the total cost of DWM, landfill-cost saving, and human toxicity are regarded as the least crucial factors with the lowest importance level in the AHP hierarchy. In the next phase, we will conduct the case study to compare four different alternatives using the developed framework.

## FIGURE/DATA



Figure 1 Criteria weighting using AHP method

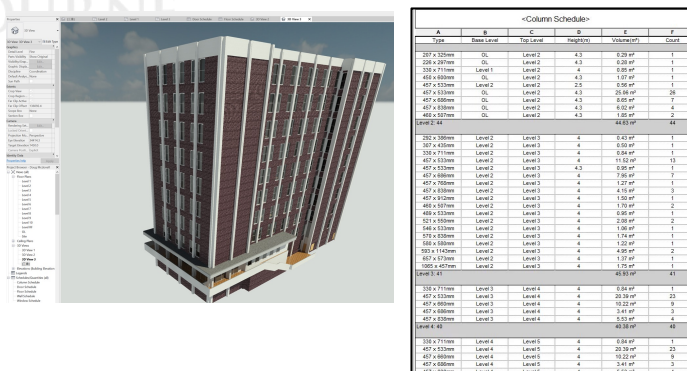


Figure 2 BIM model and material quantification

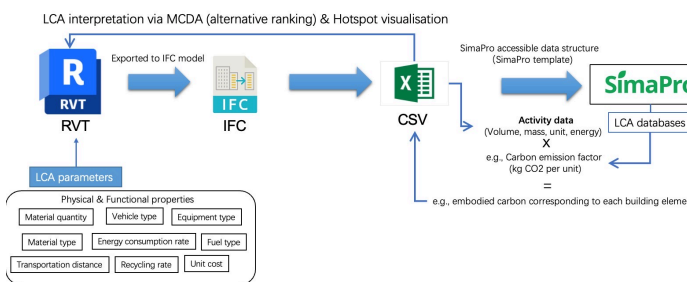


Figure 3 Framework of BIM-based sustainability assessment





# A framework to integrate BIM with artificial intelligence and machine learning-based property valuation methods

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## ABSTRACT

Property valuation is of extreme importance since variations in the real estate market enormously influence people's life. The main goal of Automated Valuation Models (AVMs) is to calculate the market value of a large number of properties with an acceptable accuracy. However, reliable data sources are required for the implementation of AVMs. Building Information Modelling (BIM) is a rich source of precise information on different components of properties. Hence, this study provides a framework that consider BIM capabilities to be integrated with different stages and processes in property valuation, especially in relation to the advanced AVMs based on Artificial Intelligence (AI) and Machine Learning (ML).

## INTRODUCTION

3D features significantly affect the value of the properties from both structural and visual aspects. Hence, 3D modelling and 3D GIS should be used for the collection of data and information on different value-related 3D features to establish the required data bases for advanced AVMs. Among different 3D models, BIM provides precise information on different components of buildings. Hence, it could be considered as a rich source of information for valuation purposes. Some scholars have tried to introduce or use BIM for property valuation practices. However, BIM benefits for different stages of valuation process and its integration to advanced AVMs based on AI and ML have not been fully investigated. Hence, this study provides a framework that considers BIM capabilities to be integrated with different stages in advanced valuation procedures.

## DISCUSSION

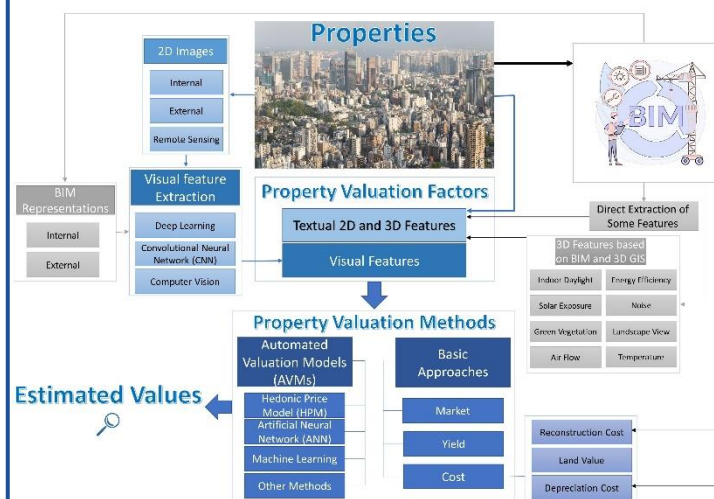
BIM as a rich source of 3D data can be used in different stages of valuation process. First, it could be used to prepare the data base that is required for the development of different AVMs. This could not only cover textual features but also include visual features. Some 2D textual features could be directly extracted from BIM. Some 3D factors can also be derived from computations and analyses through BIM and 3D GIS. In addition, BIM representations could be analyzed for the extraction of visual features using AI and computer vision. Second, computational procedures in BIM in relation to Quantity Take-Off (QTO) and Bill of Quantities (BoQ), as well as Life Cycle Analysis (LCA) and Life Cycle Cost (LCC) estimation could be employed for calculation of the components of the cost approach-based property valuation, including reconstruction cost and depreciation cost.

## METHODOLOGY

Two main concepts are important in the valuation process, including valuation methods and valuation factors. Regarding the method of valuation, three basic approaches of valuation include market, income and cost approaches. Regarding the AVMs, Hedonic Price Model (HPM) is the most widely used method. In addition, researchers have attempted to develop more advanced methods utilizing AI and ML techniques.

Besides, real estate valuation is a complex process that should consider different value-related variables, such as structural, geometrical, locational, environmental, socio-economic and legal factors. In addition to these important factors, some scholars also use AI, computer vision and deep learning to extract some visual features from image data, including internal images, external images and remote sensing data, to enhance the predictive performance of the AVMs.

## FIGURE/DATA





# Advancing Land Administration Systems Design -Required Parameters and Implications of Global Initiatives

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## ABSTRACT

Land is the ultimate resource that needs to be managed in sustainable ways. Land Administration System is a fundamental component of any country’s social, economic, and environmental aspects. Land Administration Systems are also extremely important for disaster management, improving resilience, and meeting Sustainable Development Goals-(SDGs). However, the right systems must be designed to be successfully implemented. Current Land Administration Systems may not always be efficient and adequate to overcome societal challenges and their requirements. Therefore, the Land Administration Systems are needed to be reformed and redesigned. Discussing the advancement of the land administration systems to improve Land Administration efficiency and aligned with the current trends and the implications of new technology on land and support sustainability and community resilience is the aim of this research.

## INTRODUCTION

The simple definition of land administration is “Implementing land management policies by recording, determining, and informing the public about tenure, value, and use of land”. Countries need an effective and modernized LAS to achieve SDGs. The aim of this research is to propose the required parameters for designing an effective Land Administration System by considering the implications of new technology and the latest global initiatives on land. In addition, updating global information about Land Records to assist decision-makers.

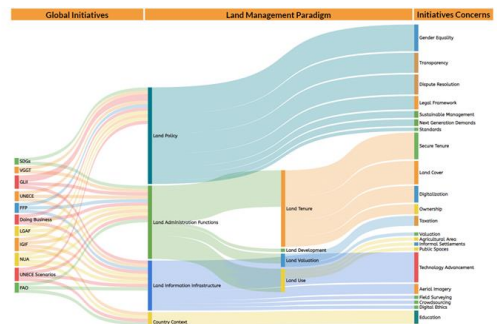
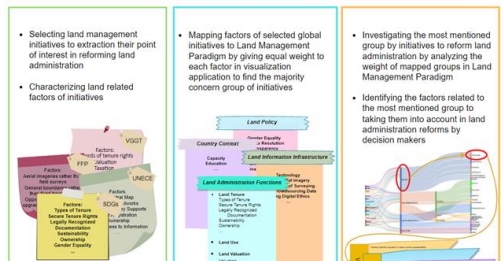
## METHODOLOGY

In this research, two phases are involved. The first phase is related to developing a methodology to help land administration reform, and the second phase focuses on updating global information on land records. To advance the Land Administration System and reform it, this research will investigate the influential factors on the Land Administration System based on the Literature Methodology and uses the Decision-Making method to identify the most influential factors. Also, for the second phase, this research will ask the knowledgeable persons of each country to give needed information.

## DISCUSSION

Global selected initiatives include the most influential land community frameworks, reports, and tools. The mapping of the factors of the mentioned initiatives in the Land Management Paradigm shows land policy as the first concern of initiatives. Next, the initiatives discuss the importance of land tenure and a cadastral system for sustainability and resilience. This study recommends that decision-makers focus more on land policy and land tenure, along with its indicators, in order to reform LASs. Thus, LASs are most concerned with ensuring secure tenure and ownership, which is the most important function of the initiatives implemented around the world.

## FIGURE/DATA







# PROOF OF LOCATION IN DISTRIBUTED LEDGER SYSTEMS

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## ABSTRACT

Distributed ledger location systems that can potentially complement traditional location services are rapidly emerging. A key feature claim of these ledgers is that they can provide location information independent of a central authority. This feature is assumed to offer decentralised proof of location (dPoL). However, there is a knowledge gap around a definition for proof of location (PoL) and no model exists for measuring or assessing PoL claims. This research addresses the knowledge gap around a definition for PoL with a literature review based on keyword searches and the construction of a PoL model from three Delphi surveys of experts in location verification.

## INTRODUCTION

Currently, there is no tool for measuring the performance of emerging location systems that develop outside the scope of traditional systems and rely, at least in part, on an alternative authority, such as consensus. The aim of the experiments in this research are to model accepted location proof in traditional systems to arrive at a tool equipped to audit and assess systems that are not wholly reliant on a central authority.

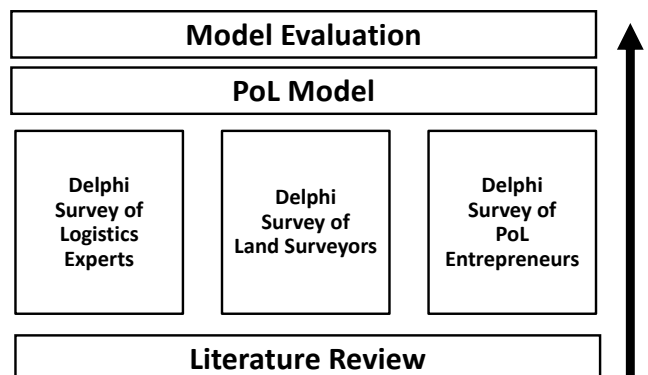
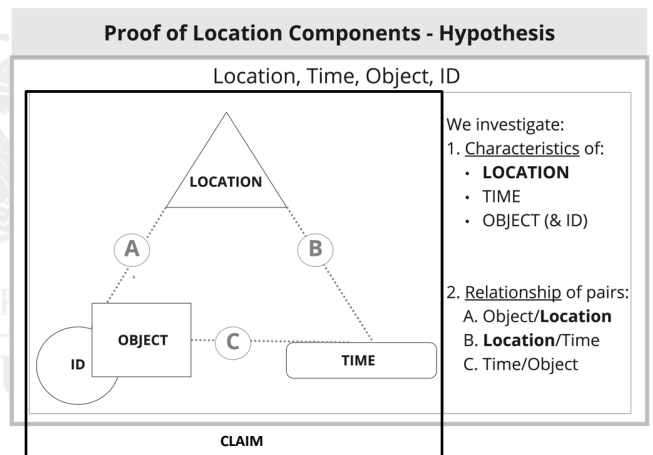
## METHODOLOGY

First, a literature review based on keyword searches was conducted to define proof of location. Then, three experiments are undertaken within the confines of a series of Delphi surveys to collect information from experts in the field of pickup/delivery, permanent reference survey marks (PRSMs) and distributed proof of location (dPoL) entrepreneurs. The results are used to build a model of proof of location in traditional location services. The model and the model approach will then be evaluated and measured for effectiveness.

## DISCUSSION

No definition or model for proof of location exists. We first defined proof of location through a literature review based on keyword searches. Next, a model for proof of location is extracted from the results of the Delphi surveys of experts in three different fields. The outcome from the literature review has led to an expansion of our hypothesis to include 'claim' as one of the key components of proof of location. Two more Delphi surveys are to be completed and the model and model approach will be evaluated.

## FIGURE/DATA





# Automated Delineation of the Agricultural Fields Using Multi-task Deep Learning and Earth Observation Data

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## ABSTRACT

The agricultural field boundary information is an essential input to crop type mapping, growth monitoring, crop yield prediction, and agricultural resources statistics estimation. Consequently, it plays a significant role in managing agricultural production more sustainably and ensuring food security in time. *Despite their importance, availability of cropping field boundary information is limited.* The advancement in Earth observation (EO) data, deep learning (DL) algorithms show increasing interest in automated boundary delineation. This research presents a multi-task DL approach to delineate agriculture fields from medium-resolution satellite images with promising results expressed in terms of thematic and geometric metrics. The developed models and results will further be examined for their robustness.

## INTRODUCTION

Agricultural field boundary information has been an integral part of precision agriculture and digital agricultural services. Traditional methods of delineating the boundaries of cropping fields are done by field survey and visual interpretation of remote sensing images, which are labour-intensive and time-consuming. Recently, more focus has been given for automated extraction of agricultural fields using DL algorithms. In this research, a multi-task learning method is used to improve the shape and boundary of segmented field boundaries.

## METHODOLOGY

The field boundaries of Île-de-France region of France are delineated by using monthly composite of Sentinel-2 images. The boundary data for training and validation are collected from [EuroCrops](#). A multi-task method can learn robust and universal representations, resulting in better knowledge sharing between tasks, and improved performance. Thus, a multi-task DL architecture is designed, where three annotated masks related to agricultural fields: extent mask, boundary mask and the distance mask are used. The accuracies are expressed by using thematic and geometric metrics (Figure 2).

## DISCUSSION

- Multi-task DL method to learn high-level boundary and shape information of the agricultural fields.
- Computationally efficient (less number of parameters) than many existing field boundary delineation models.
- Effective in delineating fields with irregular shapes and small sizes.
- The use of boundary and distance mask aid in improving the geometric accuracy of extracted fields.
- A potential solution for agricultural field delineation and digital agricultural services.

## FIGURE/DATA

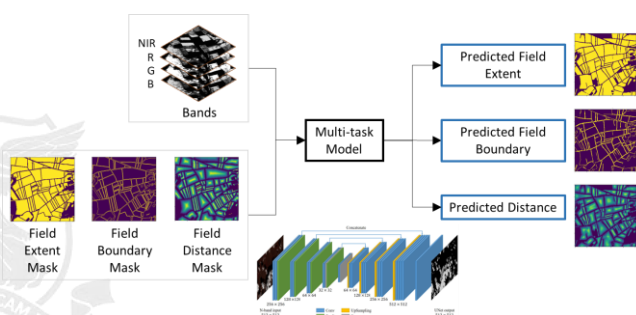


Figure 1 Multi-task DL model.

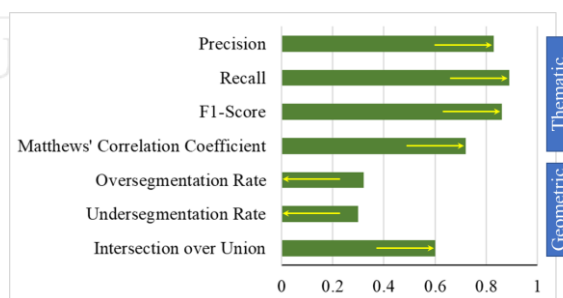


Figure 2 Accuracy assessment metrics (arrowhead points to the optimal values).



Figure 3 (a) Sentinel-2 RGB image used for field boundary delineation; (b) segmentation result from multi-task DL algorithm; (c) extracted field boundary in vector format.



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## ABSTRACT

Geometric shape classification and semantic segmentation of spatial data are non-trivial tasks in computer vision and spatial analysis. Traditional deep (convolution) neural networks designed for image/raster data have special geometric priors (i.e., shift and scale invariance/equivariance) built into the model architectures. Extending existing representation learning architectures to 2D/3D non grid-like spatial data, such as vector polygons and lidar point clouds, require a new set of learning models/tools respecting different underlying geometric priors (i.e., permutation invariance/equivariance). Hence, we are investigating a collection of novel deep learning models based on the theory of geometric deep learning for spatial data. We concretely study graph representation learning and graph neural network architectures for 2D/3D spatial data and how satisfying geometric priors of input data can aid in model learning performances.

## INTRODUCTION

Geometric deep learning (GDL) explores fundamental principles of objects: *symmetry* and *scale separation*. We investigate the symmetries (i.e., permutation invariance and equivariance) of discrete spatial data (lidar point clouds and vector polygons) and how to design novel deep neural network architectures that satisfies underlying geometric priors (symmetry groups) for representation learning and spatial tasks (i.e., spatial object segmentation and classification). Our research hence provide theoretical contributions to spatial data representation learning and empirical contributions to spatial learning tasks.

## METHODOLOGY

Our methodology includes two work packages: **WP1**. We propose a novel graph representation learning model, which allows for aggregating local and global geometric features from  $k$ -hop neighbours of point-cloud-converted graphs for large-scale lidar point cloud segmentation. **WP2**. We examine different spatial data rep. (i.e., grid, set, graph and complete graph) and network arch. (permutation vs. translation invariant models) combinations for geometric shape classification of vector polygons. We test the effective robustness and model generalization of data/model combinations on a polygonal building footprint dataset.

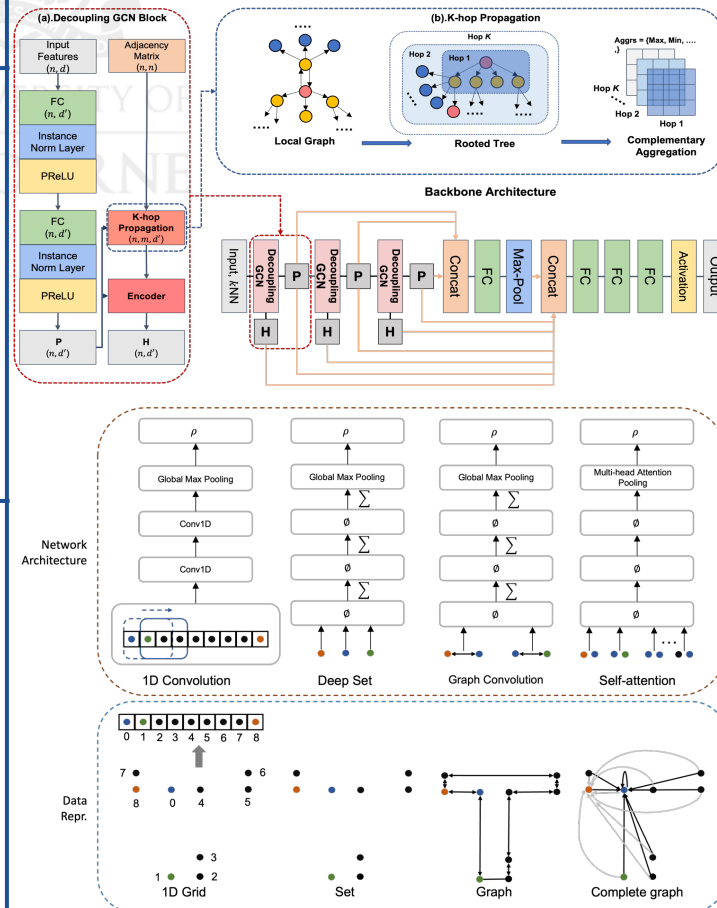
## DISCUSSION

Representation learning models have built-in learning components that respect the underlying symmetry group. Our proposed model architecture (second figure), the Decoupling GCN, satisfying permutation equivariance, enables local and global feature aggregation in a single layer for lidar point cloud segmentation. We depict the grid, set, graph and complete graph representations of vector polygons (bottom figure). Empirical results suggest that graph representation with concrete edge information enables robust shape classification and generalizable feature learning for vector polygons.

## FIGURE/DATA

Model	Domain	Symmetry group
Raster	Grid	Translation
Vectors	Simplicial Set	Permutation, Rotation $SO(2)$
TINs	Graph	Permutation
Points	Set	Permutation, Rotation $SO(3)$

Table 2.1: Spatial data models.



# Aligning the Real and the Virtual World: MR Localisation Using 3D-3D Model Registration



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## ABSTRACT

Existing camera localisation methods for indoor mixed reality (MR) are almost exclusively image based. Image-based methods do not scale well and, therefore, MR applications are mostly limited to small-scale (room) experiences. On the other hand, although we are witnessing significant improvements in automated coarse-to-fine 3D-3D model registration methods, these have not yet been applied to camera localisation in MR. This research proposes the first indoor MR localisation approach based solely on 3D-3D model registration, based on the automated learning-based registration of a low-density model of the surroundings created by the device to the existing point cloud of the environment. Extensive testing and analysis with real-world experiments is undertaken using a prototype developed for the Microsoft HoloLens.

## INTRODUCTION

The approach is the first to propose solving the MR localisation solely with learning-based coarse-to-fine 3D-3D model registration. The low-density polygonal mesh model created by the MR device is cropped to represent the user's immediate surroundings and registered to the existing point cloud. Coarse registration is performed by feature detection and description with a neural network, followed by RANSAC and fine registration with ICP. Performing the registration is an equivalent of finding the six DoF camera pose relative to it.

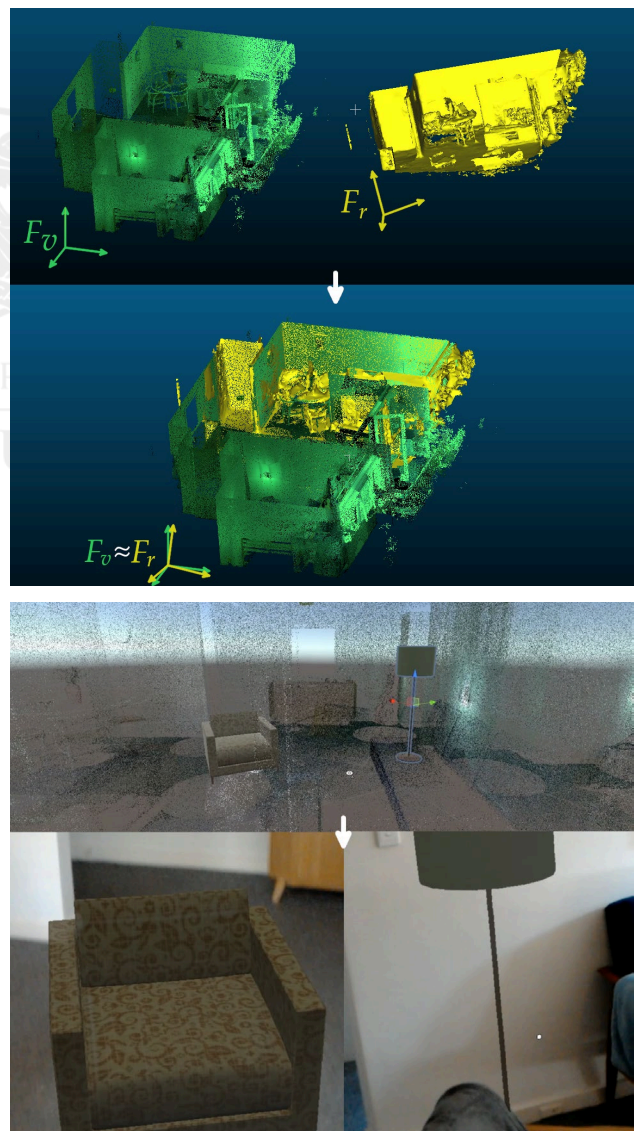
## METHODOLOGY

Experiments were conducted on two testing sites: a fully furnished 50 m<sup>2</sup> residential apartment and a 300 m<sup>2</sup>. The experiments are designed to evaluate (1) localisation accuracy, (2) localisation reliability, (3) robustness to scene changes (changes between the real and the virtual world), (4) the influence of the size of the cropped area, i.e. the size of the model being registered, (5) the influence of the maximum number of iterations within RANSAC, (6) the influence of the subsequent ICP fine registration, and (7) the ability of the system to perform in a completely new environment, i.e. without a prior source model.

## DISCUSSION

Experimental results show high localisation reliability and accuracy, with a mean translation error of 2.8 cm and a mean rotation error of 0.94°. The method performs well in a large-scale environment (300 m<sup>2</sup>) and shows robustness to changes in scene geometry as demonstrated by a 100% localisation success rate in a scene with significant differences from the corresponding reference model. In conclusion, the proposed localisation method offers several advantages over the existing methods: high reliability, localisation accuracy and robustness to scene and geometry changes, works in large-scale environments, and does not require the building of device-specific maps.

## FIGURE/DATA





# Building footprint segmentation of the City of Melbourne using feature-increased U-Net and transfer learning

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## ABSTRACT

High-resolution earth observation data collected from satellites and unmanned aerial vehicles (UAVs) are the fundamental source of building footprint extraction. Deep learning networks such as U-Net are state-of-the-art methods for the extraction of building footprints using earth observation data. However, these methods suffer from four prominent problems: lack of context features, the requirement of a large training dataset, domain-shift problem, and computational expense. In this research, we modify the U-Net architecture by increasing the contextual information. The architecture is trained on benchmark data and a newly developed robust building footprint data from the City of Melbourne. Further, we propose a fine-tuning method incorporating various transfer learning settings and learning rates. The method tackles the domain-shift between the two datasets (28% vs. 64% F1 score before and after) with 300x less network parameters.

## INTRODUCTION

Inventories on precise and accurate building footprints are useful for planning the smart cities in which geospatial industries and local agencies are investing. Very high-resolution (VHR) earth observation (EO) imagery is the primary source of data and deep learning (DL) is the state-of-the-art method for highly accurate building footprint extraction. In this research, we improve the cross-domain robustness of the DL method by up to 37% and that of the dataset by 45%. The increased robustness of the method and standardisation of dataset are supportive to precise decision processes.

## METHODOLOGY

The proposed modification to the U-Net (Ronneberger et al. 2015) from Figure 1 increases the large-scale feature maps ( $X_{En}^3, X_{En}^4, X_{En}^5$ ) in the encoder ( $En$ ) of U-Net and halves the number of filters in the decoder ( $Dn$ ), reducing the network parameters. The network is first trained on the WHU Building dataset (Ji et al. 2018) and fine-tuned on 5x smaller and more complex building footprint data from the City of Melbourne that we prepare using Nearmap APIs. The proposed method (Figure 2) is based on three fine-tuning settings of transfer learning (TL1, TL2, and TL3) and three learning rates ( $1e^{-4}$ ,  $1e^{-5}$ , and  $1e^{-6}$ ).

## DISCUSSION

The modified U-Net outperforms the original U-Net (VGG encoder) with 7 million less network parameters and up to 19% higher performance (Table 1). The proposed dataset is 31-45% more robust than the benchmark (WHU) dataset in cross-domain validation due to the variability (includes both low-rise and high-rise buildings) and complexity (4x lower resolution, 250x more high-risers). The fine-tuning method with TL3 setting and  $1e^{-4}$  learning rate tackles the domain-shift between the two datasets (28% vs. 64% F1 score before and after) and reduces the network parameters by 300x. The outcome of the research provide a more reliable method to support the decision processes.

## FIGURE/DATA

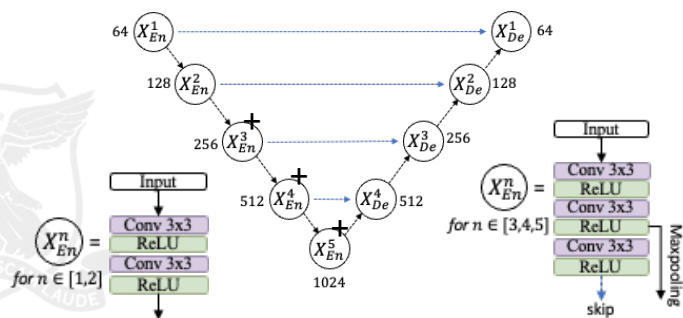


Figure 1. The network architecture of the modified U-Net.

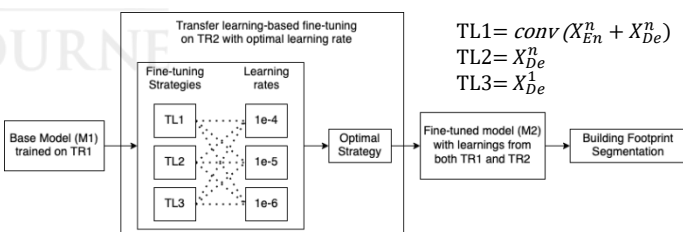


Figure 2. The proposed method to tackle the four problems of DL-based semantic segmentation.

Table 1. Same-domain and cross-domain validation of the modified U-Net on TR1 (WHU) and TR2 (City of Melbourne) datasets compared to U-Net. M1 refers to the modified U-Net trained only on TR1 and tested on TR2 before fine-tuning. M2 refers to M1 fine-tuned on TR2 with different three transfer learning settings (TL1, TL2, and TL3). Setting TL3 achieves the highest accuracy measures with a learning rate of  $1e^{-4}$ .

Evaluation Metrics	Mod. U-Net		U-Net		M1	M2		
	TR1	TR2	TR1	TR2		TL1	TL2	TL3
Train Params	23,949M		31,037M		-	23,943M	9,229M	0.109M
Non-train Params		5504		3968		0.011M	14,726M	23,846M
Steps	57,720	48,980	57,720	48,980	-	48980	48980	48,980
Time/step (ms)	321	291	365	345	-	291	194	119
Pixel Acc.	0.973	0.938	0.973	0.928	0.907	<b>0.944</b>	0.933	0.943
Average Acc	0.847	0.730	0.826	0.724	0.550	0.743	0.735	<b>0.745</b>
F1 score	0.834	0.622	0.844	0.437	0.275	0.643	0.619	<b>0.643</b>
IoU	0.761	0.532	0.770	0.342	0.217	<b>0.552</b>	0.521	0.551
MCC	0.688	0.425	0.681	0.419	0.156	0.447	0.416	<b>0.447</b>





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**Discipline:** Geomatics

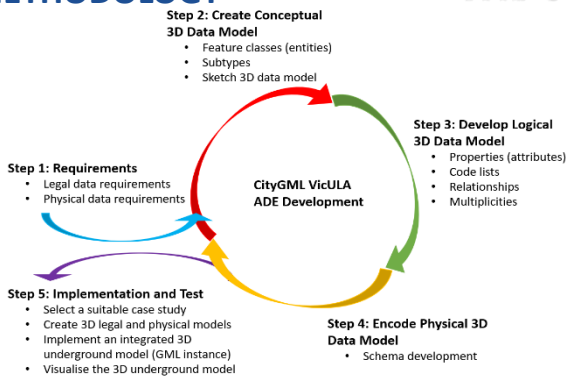
## ABSTRACT

Rapid development of underground space necessitates the efficient management of underground areas. Current Underground Land Administration (ULA) practices mainly focus on representing only either legal spaces or the physical reality of subsurface objects using fragmented and isolated 2D drawings, leading to ineffective ULA. A complete and accurate 3D representation of underground legal spaces integrated with the 3D model of their physical counterparts can support different use cases of ULA beyond underground land registration, such as planning, design and construction of underground assets, utility management and excavation. Data modelling plays an underpinning role in integrating and managing underground physical and legal data. Therefore, the aim of this research is to develop a 3D underground data model to enable integrated management of underground assets by linking legal spaces to the physical reality.

## INTRODUCTION

Extending a 3D city model to support legal data can potentially provide a viable approach for developing a 3D integrated model. CityGML is a prominent semantic data model to represent 3D urban objects at a city scale, making it a good choice for underground because underground assets such as tunnels and utilities are often modelled at city scales. However, CityGML, in its current version, does not support legal information. This research develops an Application Domain Extension (ADE) for CityGML 3.0 (VicULA) to support 3D ULA based on the requirements identified in the Victorian state of Australia.

## METHODOLOGY



## DISCUSSION

CityGML can be used to create 3D digital property maps across an entire city, jurisdiction, or country. It can also be used in national systems to exchange property data. In current property maps, only 2D parcels are displayed. However, underground assets such as tunnels and utilities are usually built vertically. Therefore, these property maps fail to represent these assets' spatial and ownership data in 3D. Extending CityGML to support legal information would be a key step towards realising 3D property maps with fully integrated representations of underground legal and physical data. The method suggested in this study can be a viable approach to replicate elsewhere.

## FIGURE/DATA

```
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    <element name="undercode" name="landApplied" type="string"/>
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  </sequence>
</complexContent>
</complexType>
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<complexContent>
  <sequence minOccurs="0">
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  </sequence>
  <attributeGroup ref="gml:AssociationAttributeGroup"/>
  <attributeGroup ref="gml:OwnershipAttributeGroup"/>
</complexContent>
</complexType>
```

Depth Limitation

Figure 1. Snippets of the XML schema of the VicULA ADE

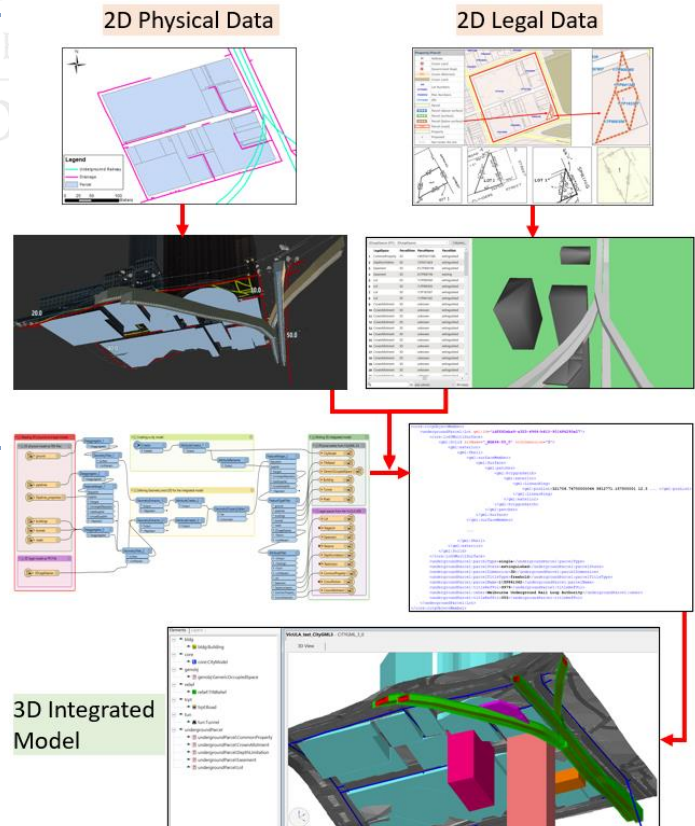


Figure 2. Implementation and test





# A Morphology based integrated approach for urban sprawl management to support sustainable cities

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**Discipline:** Geomatics

## ABSTRACT

Sustainability of cities globally are threatened by increasing rate of urban expansion. Urban Sprawl is the city development phenomenon characterised by low density, single land use and private car dependency. Cities around the world have not been able to limit urban sprawl due to absence of integration between morphological elements and strategic influences. This study aims to formulate an integrated framework for urban sprawl management using typo-morphological approach and scale hierarchy. The developed framework will be validated on three cities of Melbourne, Flanders and Kathmandu. The outcomes will assist urban planners and policy makers in making informed decisions for urban sprawl management which would support in achieving Sustainable Development Goal (SDG11).

## INTRODUCTION

Urban Sprawl is the rapid horizontal expansion of city characterised by low density, dispersed settlement structure, single land use and private car dependency. Large extent of land consumption and excessive travel, brought about by urban sprawl have adverse consequences towards sustainable development. Cities worldwide have not been able to regulate this issue due to absence of an integrated approach to its management including identification of morphological aspect, the relationship between urban policies and governance model.

## METHODOLOGY

Following the worldview of pragmatism and nomothetic approach, integrated framework for urban sprawl management shall be formulated inductively by means of case studies of Melbourne, Flanders and Kathmandu.

- Thematic document analysis using typo-morphological approach and theory of scale hierarchy.
- Case studies using geospatial techniques.
- Relevant policy evaluation with particular focus on the three case studies.
- Formulation of integrated framework for urban sprawl management by building logical chain of evidence.

## DISCUSSION

Morphology of urban sprawl generally include leapfrog/scattered development, commercial strip/ ribbon development and low density/single use development. This study is expected to further explore typo morphological layers such as building, street, plot, open spaces for parcel, plot, district and regional scale that characterise urban sprawl. Influential policies and planning schemes for urban sprawl include urban growth boundary, green belt, land use regulations, transit oriented development. The framework to be formulated integrating these aspects for urban sprawl management will support sustainable city development.

## FIGURE/DATA

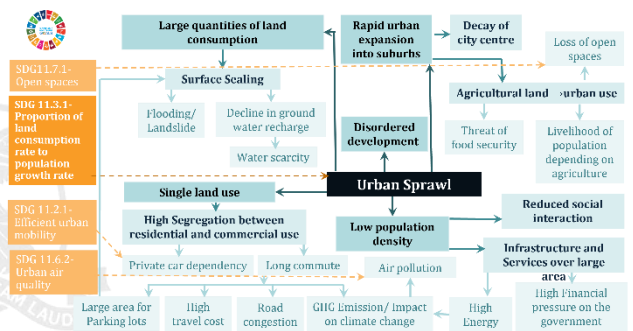


Figure 1: Urban sprawl and sustainable development

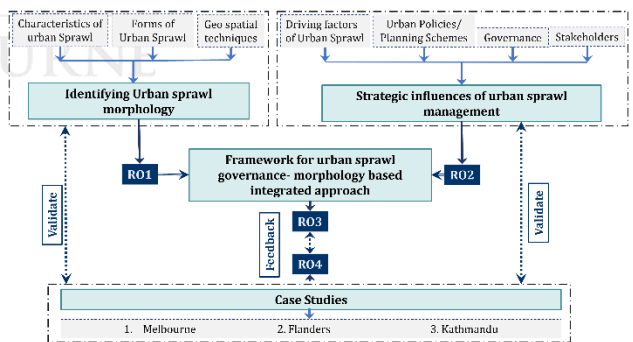


Figure 2: Methodological framework

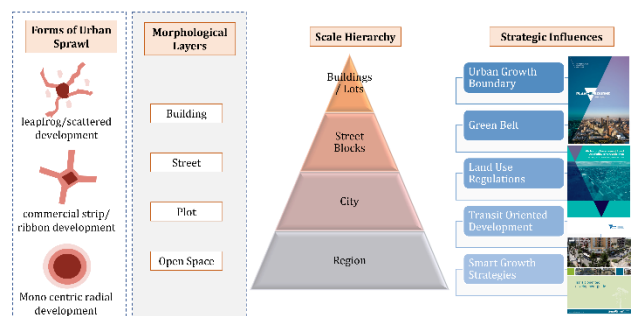


Figure 3: Integrating urban sprawl morphology and strategic influences

<sup>1</sup>Joint PhD Student between UoM and KU Leuven

\* PhD Confirmation Seminar will be on end of Nov. 2022





# THE DIGITISATION OF REPAIRS AND MAINTENANCE IN MEDIUM-RISE AND HIGH-RISE STRATA-TITLED RESIDENTIAL APARTMENTS IN MELBOURNE/ GREATER MELBOURNE VIC.

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**Discipline:** Department of Infrastructure Engineering (Geomatics)

## ABSTRACT

Apartment owners are legally responsible for the repair and maintenance of the building envelope, all common areas and the land surrounding their apartments. Preliminary research suggests that despite being legally responsible for this work, these owners (known collectively as Owners Corporations or OC's) are very poorly equipped with respect to the construction information of their buildings. The aim of my research is to identify what digital building information should be included in the handover of residential developments. The identification of this information is to be determined by asking the owners and managers of five existing apartment buildings what building information they need and how this information should be provided to them.

## INTRODUCTION

Karen is an architect with over twenty years in the use of BIM software in projects ranging from domestic renovations to high-rise residential and mixed-use apartment developments. Since 2016, Karen has been consulted on a variety of complex building issues faced by strata-titled residential Owners Corporations, including protection works notices, building orders, building notices, substantial repairs and refurbishment work. Karen is also an apartment owner and has been actively involved in her own Owners Corporation Executive Committee having held the positions of Chair, Treasurer and Board member.

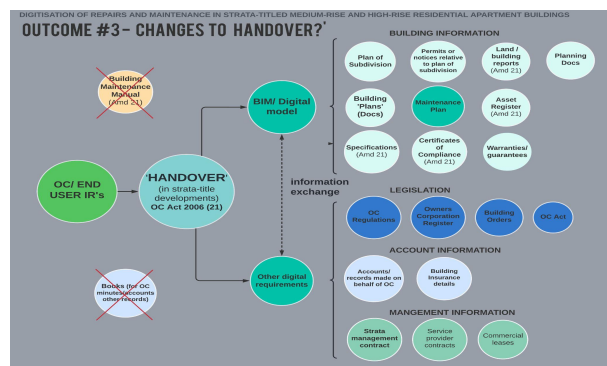
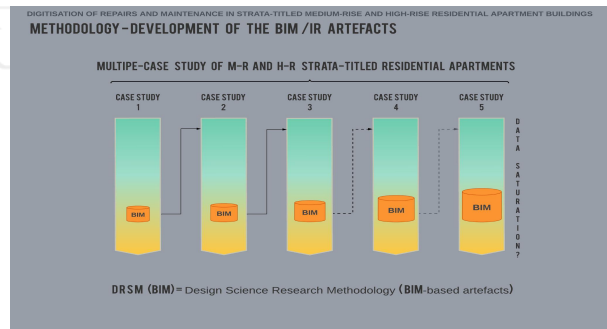
## METHODOLOGY

A mixed methods, multiple case-study methodology over laid by case-based Design Science Research Methodology (DSRM) has been adopted for this research. This provides for the use of both quantitative and qualitative methods. DSRM is to be used to develop two 'artefacts' - a specification of information requirements suitable for inclusion at the design stage of residential buildings and the testing of a BIM-based solution best suited to management of repairs and maintenance in this context.

## DISCUSSION

The inherent complexity of strata-titled apartment developments makes it difficult to apply accepted BIM standards such as (AS) ISO 19650: *Organisation and digitisation of information about buildings and civil engineering works including building information modelling (BIM) Information management using building information modelling*. Most notably, neither the Owners Corporation/ owners are the project 'client' so they have no say in the identification of information requirements they will need. This has a significant impact on the development and use of digital solutions best suited to the 'operational' phase of these buildings during their lifetime.

## FIGURE/DATA







# Lidar indoor relocalization, navigation and change detection of building interior

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**Discipline:** Geomatics

## ABSTRACT

Existing indoor lidar navigation systems require the initial pose of the lidar sensor and the ability to recover from localization failure. I propose MoLi-PoseNet to perform relocalization using a 3D model based on deep learning. Lidar odometry enables localizing vehicles and robots in the environments where global navigation satellite systems (GNSS) are not available. Current approaches heavily rely on loop closure to optimize the estimated sensor poses and to eliminate the drift of the estimated trajectory. I propose MoLO-drift free lidar odometry using a 3D model. Detecting changes of an indoor environment with respect to an existing 3D model is a critical procedure for applications such as building facility management, navigation, and emergency response. I propose an interior structural change detection method using a 3D model and lidar segmentation.

## INTRODUCTION

MoLi-PoseNet estimates the pose of the lidar sensor using a convolutional regression network trained with synthetic scans generated from the surface-based 3D model.

MoLO: a novel model-based lidar odometry approach to eliminate drift in real time by performing relocalization with a 3D model.

A change detection network with two inputs is built for synthetic lidar scans and real lidar scans respectively. The change detection network classifies each point of real lidar scans into one of four categories: unchanged, structural change, moving object and temporary change

## METHODOLOGY

MoLi-PoseNet: a simulated lidar is placed in the 3D model to generate synthetic lidar scans with known poses the acquired real lidar scan will be input into the trained convolutional regression network to estimate the current lidar pose

MoLo: The acquired lidar scans are registered with the 3D model at a certain frequency to estimate the lidar pose without drift

Change detection: The pairs of real lidar scans and synthetic lidar scans are used to train the built two-branch lidar segmentation network.

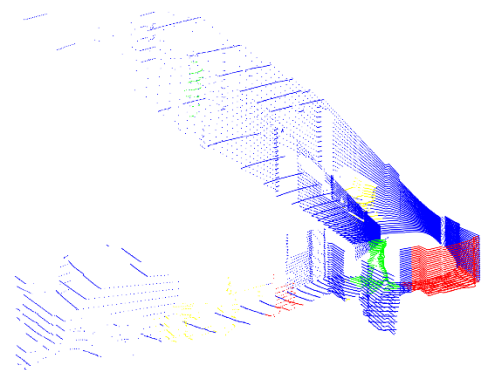
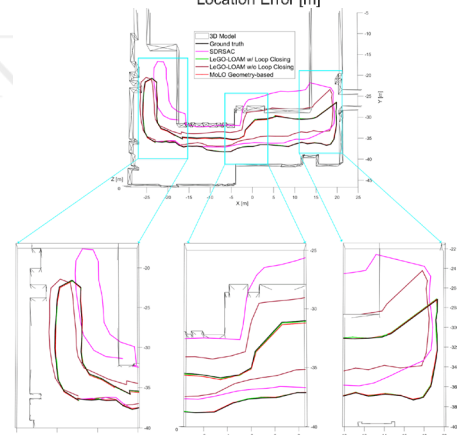
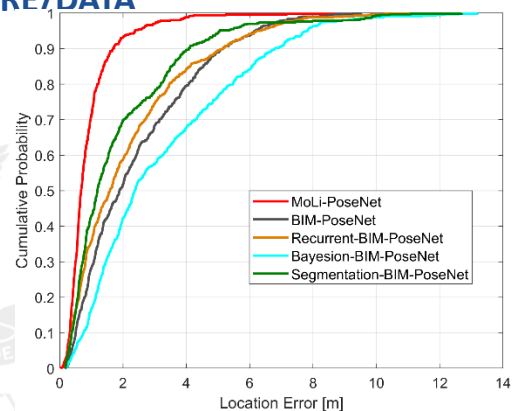
## DISCUSSION

MoLi-PoseNet: MoLi-PoseNet can achieve meter-level relocalization accuracy in large indoor environments with low-level-of-detail models.

MoLO: MoLO can eliminate drift and achieve real-time localization while providing an accuracy equivalent to loop closure optimization.

Change detection: the proposed approach can detect and classify the real lidar points to 94% overall accuracy and results demonstrate that the trained network is transferable to comparable environments.

## FIGURE/DATA





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**Supervisor(s):** Dr Amir Khodabandeh, A/Prof Kourosh Khoshelham  
**Discipline:** Geomatics

## ABSTRACT

The ionosphere has been considered as one of the primary sources of errors in Global Navigation Satellite Systems (GNSS) signal propagation, and it is still challenging to model it precisely, particularly for real-time positioning applications. This research aims to provide a realistic spatiotemporal model of the ionosphere in order to obtain real-time precise positioning. This study considers the ionosphere as a nuisance parameter and puts emphasis on 'ambiguity-resolved positioning', thus aiming to quantify the extent to which ionospheric modelling can improve the positioning user Integer Ambiguity Resolution (IAR) performance. The ionosphere-parametrization is used to reduce the number of unknowns for the physical model of the ionosphere. Therefore, it strengthens the measurement model and enhances the positioning accuracy.

## INTRODUCTION

The ionosphere is the upper atmosphere region located at the height of approximately 50 km to 1000 km. The free electron density in the ionosphere encounters severe variations in time and space, primarily coming from solar ultraviolet and X-ray radiation. The presence of these free electrons adversely affects the propagation of GNSS signals and positioning accuracy. The modelling of ionosphere is essential to fulfil the needs for real time precise positioning. This research aims to develop a spatiotemporal model of the ionosphere for the Victorian state of Australia.

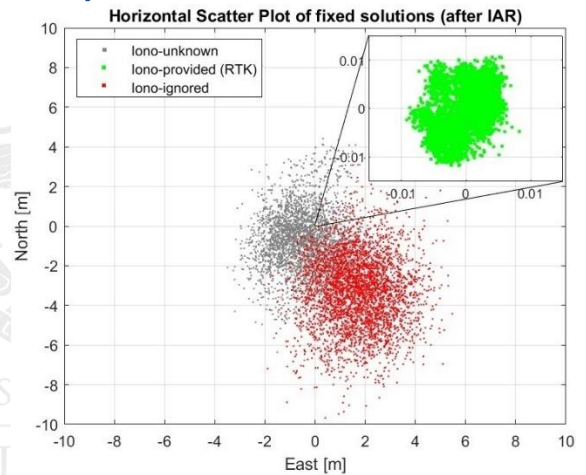
## METHODOLOGY

- Step 1:** Investigating the strengths and weaknesses of existing spatial, temporal, and spatiotemporal ionospheric models,
- Step 2:** Modelling 'temporal' variation of ionospheric delays experienced by a single GNSS receiver,
- Step 3:** Modelling 'spatial' variation of ionospheric delays simultaneously experienced by multiple (a network of) GNSS receivers, and
- Step 4:** Modelling 'spatiotemporal' variation of ionospheric delays experienced by multiple (a network of) GNSS receivers.

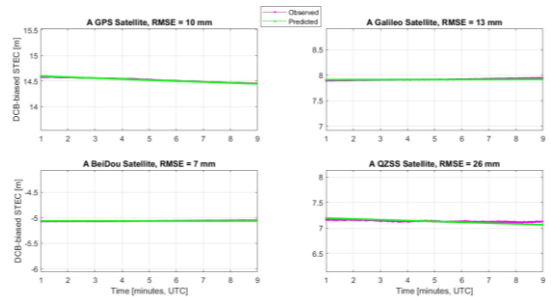
## DISCUSSION

Although GNSS code measurements are easily accessible, their carrier phase counterparts provide more precise parameter estimates. However, using carrier phase measurements is challenging because they are biased by unknown integer-valued ambiguities and instrumental phase delays. If the reference station provides satellite clocks, phase biases, and ionospheric corrections to the user receiver, the user can apply IAR. Therefore, the ambiguity success rate will be sufficiently high to permit near real time positioning. In contrast to existing studies, this research considers the ionosphere as a nuisance parameter and puts emphasis on 'ambiguity-resolved positioning'.

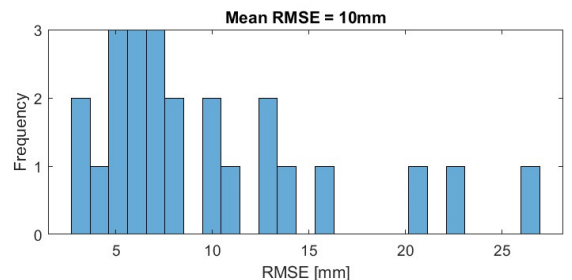
## FIGURE/DATA



**Figure 1:** The horizontal position scatter plot after IAR.



**Figure 2:** The observed and modelled DCB-biased STEC using ionosphere-parametrization.



**Figure 3:** The RMSE histogram of multi-GNSS satellites using ionosphere-parametrization.





# Study of faculty staff undertaking an on-Country experience to bridge western and Indigenous worldviews – Research design

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**Discipline:** Geomatics (but really Engineering Education)

## ABSTRACT

Across Australia there is an increasing focus on integrating Indigenous knowledges and perspectives into higher education curricula, including engineering education. This presentation outlines the rationale and design of a study that aims to test and further develop a curriculum development model for embedding Indigenous perspectives into engineering curricula. Extending on the work of Goldfinch et al (2017), the study focuses on exploring how attitudes of university staff are influenced by an on-Country experience with Indigenous knowledge holders and how the experience leads to individual and collective action to integrate Indigenous knowledges and perspectives into engineering curricula.

## INTRODUCTION

In 2017, the Australian Council of Engineering Deans (ACED) released a Position Statement on embedding Aboriginal and Torres Strait Islander perspectives into the engineering curriculum. In the lead up to the ACED position statement, a separate research project produced the ‘Engineering Across Cultures’ (EAC) curriculum development model. This study aims to further test and develop the EAC curriculum development model.

This presentation will outline the rationale and design of the study and discuss how we might move towards decolonising methodologies in engineering education research.

## DISCUSSION

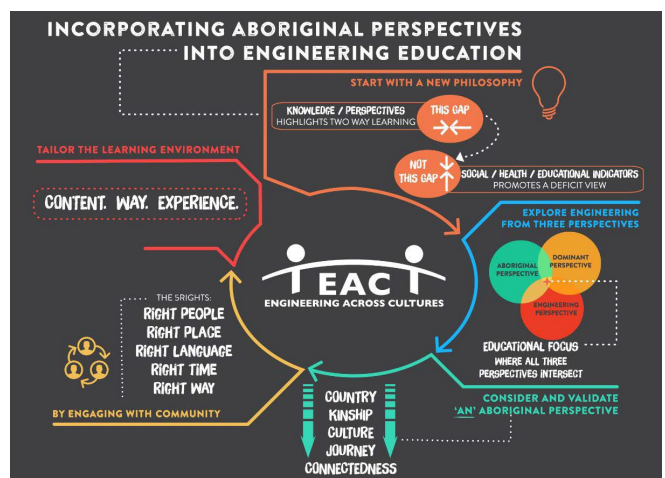
At the time of this conference, the final round of data collection was not complete. As such, this presentation focuses on the research design only.

Designing research in this field is complex and contested. As we navigate the complexities of integrating different knowledges into engineering education, we also need to consider how we do the same thing in our research. The western knowledge creation paradigm pervades and perpetuates the way we acquire knowledge, including in much of this research. To engage with this complexity, I adopt the decolonising strategy of critique. I invited an Indigenous academic developer to critique the research design from an Indigenous knowledge and research lens. Highlights from the critique, based on a yarn (a process of respectful dialogue), will be presented.

## METHODOLOGY

Adopting an interpretivist worldview and a phenomenological approach, the study gathers data via semi-structured interviews and artifact sharing from participants. The interviews include open-ended questions and emergent approaches, using both text and image. Data analysis uses qualitative methods including thematic analysis. The study design also engages with the concept of decolonising methodologies in the context of engineering education research. This is used both to critique and strengthen the research design.

## FIGURE/DATA



EAC model (reproduced from Goldfinch et al, 2016)





THE UNIVERSITY OF  
MELBOURNE

# ENVIRONMENTAL HYDROLOGY AND WATER RESOURCES



# A new framework for adaptive monitoring of large-scale environmental management projects



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**Discipline:** Environmental hydrology and water resources

## ABSTRACT

In the large-scale monitoring program, all indicators are either monitored for research purposes, or for management purposes. Understanding how the system work is essential to facilitate the adaptive management process. However, most of current monitoring programs for research don't support the management decision-making. Therefore, we propose a new framework that links the monitoring and research via adaptive cycles and allows the iterative adjustment of monitoring resources and management action. Following the proposed framework, monitoring resources could be shifted towards more valuable fundamental environment covariates (general drivers in the ecosystem).

## INTRODUCTION

Large scale conservation interventions remain a relatively new field, and monitoring design and implementation have evolved rapidly. With limited resources, effective and efficient monitoring design has become a key research focus. There are well recognized problems with current approaches to monitoring including inappropriate objectives, imprecise understanding of the system, insufficient funding, imperfect detection during sampling, and inadequate statistical power. Consequently, with limited resources, a significant portion of monitoring projects are recognized as ineffective or inefficient.

## METHODOLOGY

Generally, large-scale environmental management projects implement actions that target specific drivers, which then impact the mean and fundamental management objective. Therefore, this research distinguished three different types of monitoring (a) compliance monitoring, (b) management monitoring and (c) research objectives in large-scale environmental management projects. We build on the traditional adaptive management framework and propose a dual loop framework that provides a clear division between the role of monitoring in (1) systems understanding and (2) adaptive management process.

## DISCUSSION

This framework can provide guidance on monitoring resource allocation and to enhance the effectiveness and efficiency in large-scale monitoring projects. Where the conceptual model linking the management action and driver through to the fundamental objective is highly uncertain, more effort is needed in monitoring means objectives and improving the conceptual model. Once the knowledge base is strong, monitoring effort can shift to the monitoring the drivers and fundamental objective outcomes. By filling the knowledge gaps, monitoring resources could be shifted towards more fundamental environment covariates (general drivers in the ecosystem).

## FIGURE/DATA

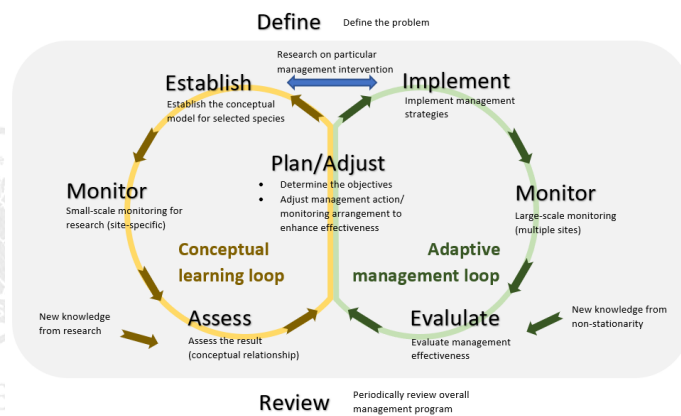


Figure: Double loops in monitoring and management programs (combining adaptive management loop with conceptual learning loop). The figure presents a logic flow of monitoring project structure: define, plan, establish/implement, monitor, evaluate/assess and adjust the plan.

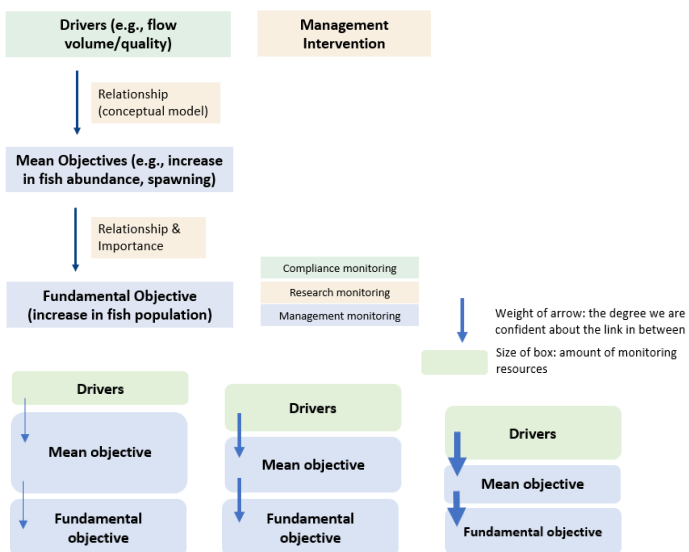


Figure: Different types of monitoring and the resources allocation process followed the proposed framework. It is expected that there would be an overall shrink in the resources required as monitoring going on.





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## ABSTRACT

Studies on population in river systems consider the effects of spatial structure of river networks on population distributions (regional effects), while local effects of dendritic river networks have been less researched. In this study, we investigated how the positions of local areas (sites/ nodes) within networks affect population densities. We conducted experiments with artificial river networks populated with *Daphnia carinata*. Results showed that the topologically equivalent networks had the same effect despite their different physical arrangements. Nodes located centrally had higher population densities, which implies that the position within the network can have an impact on local population densities.

## INTRODUCTION

Understanding the processes that drive population dynamics in river systems can inform better management. The dendritic geometry of rivers can impact movement of organisms, which may result in different population distributions compared to other types of habitat networks. Previous studies consider the effects of spatial structure of river networks on population distributions (regional effects), while local effects of dendritic river networks have been less researched. In this study, we investigated how the positions of local areas (sites/ nodes) within river networks affect population densities.

## METHODOLOGY

We conducted experiments with artificial river networks populated with *Daphnia carinata*, an easily cultured species. Networks consist of individual nodes (bottles) connected by clear tubing through which organisms can travel. Two sets of networks are built (Figure 1). Every network has 6 nodes. One group is in straight lines. The other group has altered edges direction which makes them form “S” shapes. All the networks started with 5 individuals in each node, which makes it 30 individuals for each network.

## DISCUSSION

Results showed that the topologically equivalent networks had the same effect despite their different physical arrangements (Figure 3). However, it took a longer time for the networks with smaller radius (distance from the centre to the edge of the network) to reach the same population distribution as networks with larger radius. Nodes (bottles) located centrally had higher population densities.

Results imply that the position within the network can have an impact on local population densities, potentially affecting population distributions at larger scales.

## FIGURE/DATA

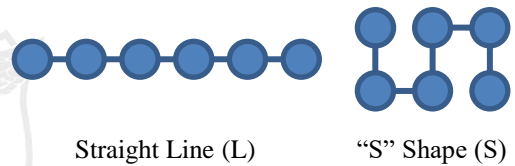


Figure 1. Network structures

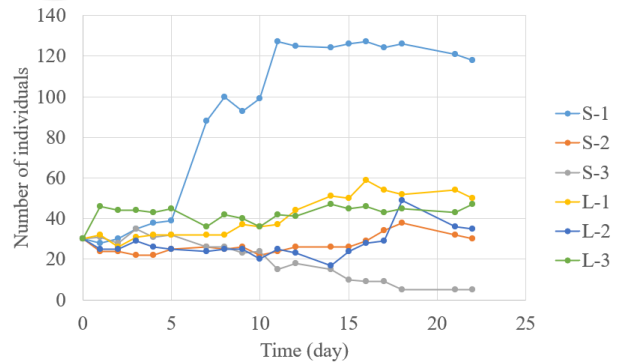


Figure 2. Daphnia populations over time

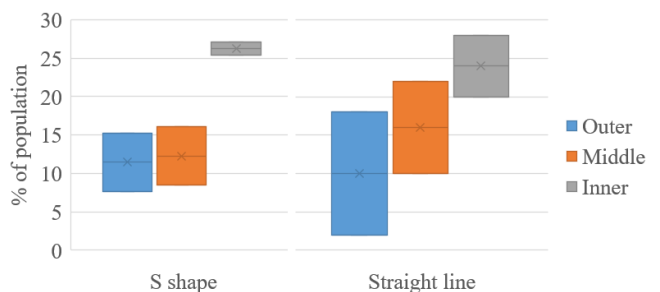


Figure 3. Daphnia population distribution (Day 22)





# Assessing the Impact of a Permanent Inland Lake on Precipitation in Central Australia

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**Discipline:** Environmental Hydrology & Water Resources

## ABSTRACT

Australia is the driest inhabited continent and water is one of the most important resources in this country. This research was inspired by a potential geo-engineering project proposed decades ago aiming at changing the rainfall regime over the continent by constructing a large evaporative pond in a semi-arid region of Central Australia. By emulating an idealised permanent inland lake in a fully-coupled global climate model, we investigated how the precipitation responded to that land surface perturbation from local to regional scales. At the local scale, the permanent lake strengthened the rainfall recycling process and slightly increase the precipitation. However, at the regional scale, the permanent lake failed to create significant impacts on precipitation although extra amount of lake-originated moisture spread over the continent.

## INTRODUCTION

Inland water bodies influence the regional water cycle via evaporation and evaporative cooling, which makes it an appealing proposal that introducing a large water expanse in the middle of arid area (like Central Australia) could potentially bring precipitation to the places where more water is urgently needed (e.g., to promote dryland agriculture). However, there is a lack of research about the underlying mechanisms of how an inland water body interacts with the overlying atmosphere and the caused changes in relevant hydrometeorological processes haven't been comprehensively assessed.

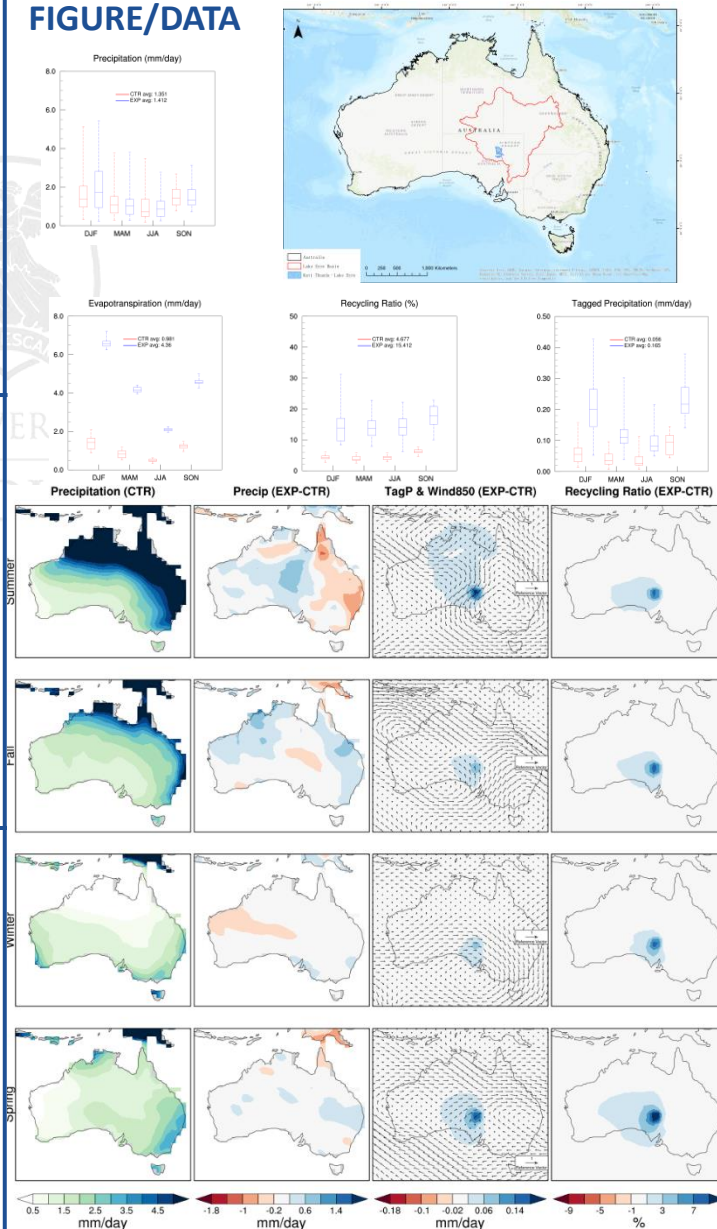
## METHODOLOGY

Kati Thanda-Lake Eyre (Lake Eyre) was chosen to be the research domain. Lake Eyre is an ephemeral lake but in this research the idealized lake was set to be a permanent one. This research employed a state-of-the-art global climate model (GCM), community earth system model (CESM), coupling land and atmosphere with sea surface temperature (SST) prescribed. Moreover, water tracers (WVTs) were enabled in the model simulation for moisture tracking. We analysed the model outputs over a 30-year period to compare the experiment (EXP, where there is a lake) with the control (CTR, where there is no lake).

## DISCUSSION

At the local scale, EXP witnessed a slight increase in the annual average precipitation while the changes in precipitation were not consistent across seasons as well as its interannual variability. On the country, the permanent lake provided considerable amount moisture into the atmosphere. Compared to CTR, there was more precipitation being recycled locally in EXP which indicates an enhanced land-atmosphere coupling. At the regional scale, the water vapor evaporated from the lake typically move to the northwest of the continent which corresponded to the behaviour of wind field at 850 hPa. However, additional moisture turned out to be a minor factor when deciding the changes in regional precipitation.

## FIGURE/DATA





# Simulating the L-, C- and X-band Backscatter from Bare Soil Surfaces Using the Advanced Integral Equation Model

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**Discipline:** Environmental Hydrology and Water Resources

## ABSTRACT

Accurate estimation of high temporal and spatial resolution soil moisture is of crucial importance for many agricultural applications. Synthetic Aperture Radar (SAR) which is highly sensitive to soil dielectric properties provides all-weather data and has the unique ability to estimate soil moisture at spatial and temporal scales that is required for most of the agricultural applications. Backscatter coefficient ( $\sigma^0$ ) is measured by SAR and the total observed  $\sigma^0$  is the contribution due to soil surface scattering, volume scattering from the vegetation and double-bounce scattering. In order to accurately retrieve soil moisture in an agricultural land, it is necessary to be able to accurately estimate the total observed backscatter and this study is done to understand the backscatter coefficient (HH, VV, HV) behavior in bare soil surface conditions.

## INTRODUCTION

Advanced Integral Equation Model (AIEM) simulates surface scattering as a function of the *soil moisture content*, *surface roughness* of bare soil, and radar configuration parameters such as the wavelength and incidence angle. The main objective of this study is to understand the behaviour of bare soil backscatter observed by L-, C- and X-band radar for single-scale roughness in bare soil surfaces with varying surface roughness conditions.

## METHODOLOGY

- Dobson soil dielectric mixing model is used to obtain the complex dielectric constant of soil with varying soil moisture content for different bands.
- Single-scale surface roughness is reproduced using an exponential spatial correlation function with root mean square height and correlation length.
- Based on the range of soil moisture and roughness conditions above, backscatter coefficients from AIEM is simulated for L-, C-, X-band and for a range of incidence angles.

## DISCUSSION

- It was observed that for a specific soil type and moisture content, higher frequency SAR observed comparatively lower dielectric values than lower frequency bands (Fig 3).
- Backscatter coefficient from bare soil surfaces is influenced by surface roughness (mainly root mean square height; Fig 6) than available moisture content.
- As coherent scattering takes place at very smooth surfaces, simulated backscatter coefficients for all the three polarizations were extremely small when compared to moderately rough and very rough surfaces (Fig 5).

## FIGURE/DATA

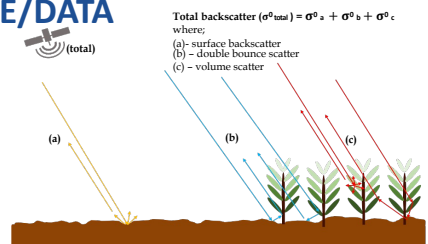


Fig 1: Radiative transfer process in an agricultural field and the contributing components to total backscatter coefficient

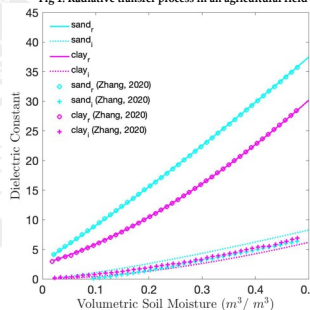


Fig 2: Comparison of dielectric constant simulation for sand and clay with results from Zhang et al., 2020

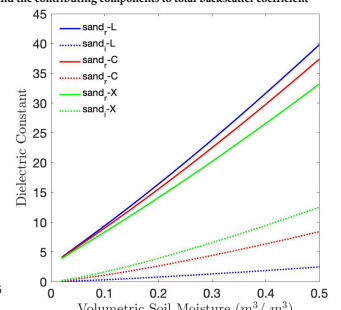


Fig 3: Dielectric constant of sand for L- (1.5 GHz), C- (5.5 GHz) and X- (9.5 GHz) bands

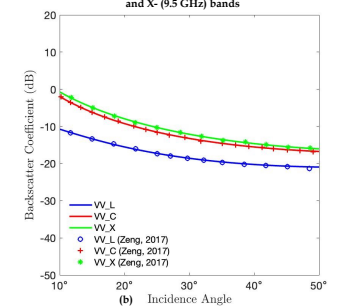
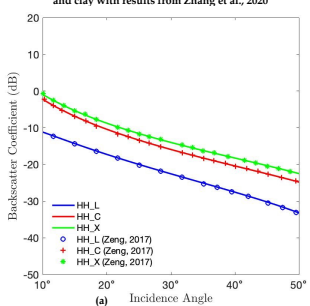


Fig 4: Comparison of backscatter coefficient simulations for L-, C-, X-band using AIEM with results from Zeng et al., 2017 for (a) HH polarization and (b) VV polarization

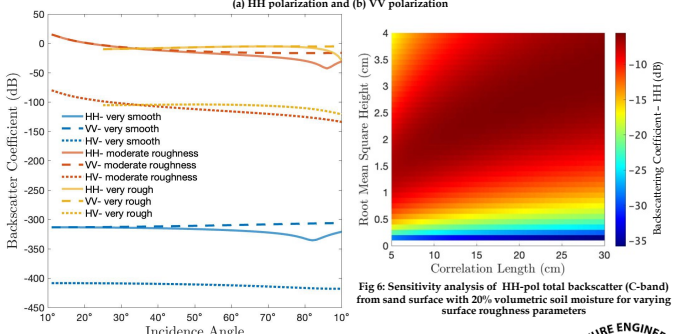


Fig 5: C-band backscatter of sand surface with 20% volumetric soil moisture with different surface roughness

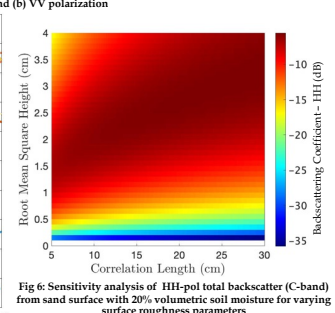
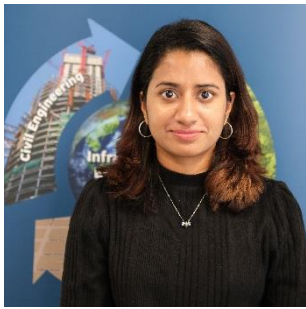


Fig 6: Sensitivity analysis of HH-pol total backscatter (C-band) from sand surface with 20% volumetric soil moisture for varying surface roughness parameters







# Partitioning of Precipitation into Terrestrial Water Balance Components under a Drying Climate

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**Supervisor(s):** Murray Peel, Keirnan Fowler, Margarita Saft, Tim Peterson, Dongryeol Ryu  
**Discipline:** Environmental Hydrology and Water Resources

## ABSTRACT

Understanding precipitation partitioning into other terrestrial water balance components is important to accurately project future water availability under a drying climate. This study focuses on understanding how evapotranspiration (AET), and change in subsurface storage ( $\Delta S$ ), respond to prolonged drought. The study employs interpolated gridded rainfall and discharge estimates with remotely sensed evapotranspiration to construct the water balance across Western region of Victoria, Australia during the Millennium Drought. Water-balance-derived  $\Delta S$  are evaluated against GRACE estimates. Both show a significant multi-year decline in storage, with GRACE exhibiting a less decline rate. AET rates remained approximately constant prior to and during the multiyear drought. Overall, with approximately constant AET, the multiyear drought reduction in precipitation was partitioned into  $\Delta S$  and streamflow.

## INTRODUCTION

Investigating how precipitation changes under a drying climate is partitioned into other water balance components is an ongoing research challenge. Partitioning of rainfall into actual evapotranspiration, runoff, and change in total soil water storage is difficult to project as each component has interlinked complex relationships with climate and catchment characteristics. This research is motivated to understand how the terrestrial water balance changes under a drying climate. The research focuses on addressing the questions of how AET and  $\Delta S$  respond to an extended multiyear drought.

## METHODOLOGY

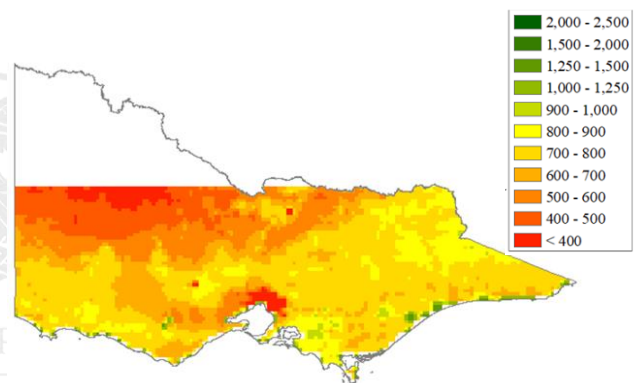
- Employ AWAP rainfall, interpolated gridded discharge estimates, and AVHRR AET from 1982 to 2012.
- Calculate gridded adjustment factors to bias-correct AVHRR AET using pre-drought (1982-1996) water balance closure.
- Apply calculated gridded adjustment factors on each individual year AET from 1982 – 2012 assuming pre-drought bias of AET is same during the whole study period.
- Construct gridded water balance and derive  $\Delta S$  across Western region of Victoria.
- Evaluate water balance derived  $\Delta S$  against GRACE.

## DISCUSSION

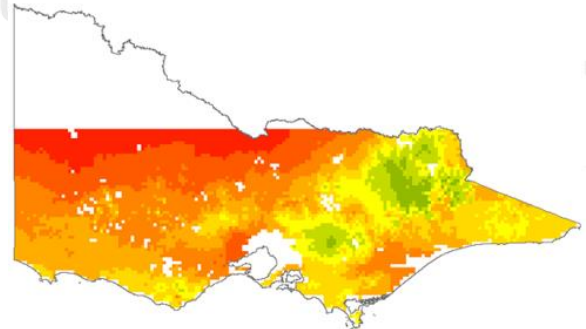
- The study shows actual evapotranspiration (AET) rates remained approximately constant prior to and during the multiyear drought while significant decline in  $\Delta S$ .
- This finding implies that the reduction of precipitation during the Millennium Drought was partitioned mainly into reductions in streamflow, soil moisture, and groundwater; in other words, terrestrial AET appeared to get priority over other water balance components.
- The significant shifts in rainfall-runoff relationship might be explained in other regions if similar AET behaviour is observed, and such behaviour has significant implications for hydrological projections under a drying climate.

## FIGURE/DATA

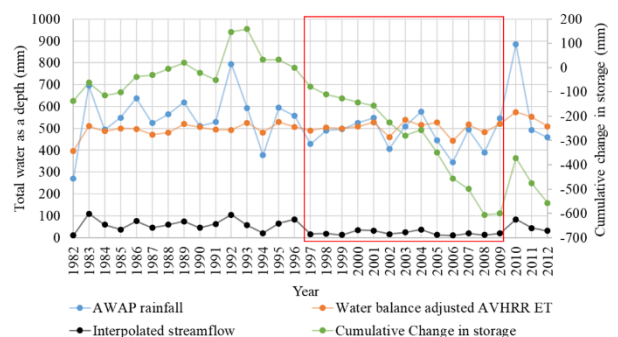
a) Raw annual average gridded AVHRR AET (1982 – 2012)



b) Adjusted annual average gridded AVHRR AET (1982 – 2012)



c) Timeseries of water balance components, and water balance derived cumulative change in storage over the West region



# Investigation of Lunisolar Signals in Precipitation over South-eastern Australia with a View to Flood and Drought Prediction



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**Supervisor(s):** Angus Webb, Andrew Western  
**Discipline:** Environmental Hydrology and Water Resources

## ABSTRACT

The objective of this research is to identify and refine the influence of lunisolar cycles on rainfall, in order to develop a model for the long-term prediction of flood and drought in South-eastern Australia. Research exists supporting the concept but remains outside the accepted doctrine of climate science. Recent studies have estimated up to 85% of extreme flood and drought events occur in resonance with lunisolar cycles, with lunar nodal cycle (18.6 years) and the sunspot cycle (~11 years) being the most frequently investigated. This presentation will focus on the initial literature review, proposed methods and initial tests.

## INTRODUCTION

The influence of decadal lunisolar cycles on precipitation has been observed in in South America (Currie, 1983), North America (Cook et al., 1997), China (Currie, 1995a), Mongolia (Davi et al., 2006), Egypt (Currie, 1995b), Russia (Currie, 1995c) and Australia (Noble & Vines, 1993; Vines et al., 2004). There are several factors which of the phenomena which remain unexplained including mechanism and prediction of the observed 180° phase change, quantification of the observed amplitude modulation and rigorous statistical proof.

## FIGURE/DATA

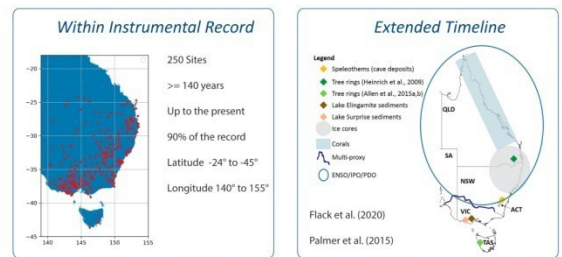


Figure 1: Location of 250 viable rainfall data sites available from the BOM in south-eastern Australia and extended timeline data

## METHODOLOGY

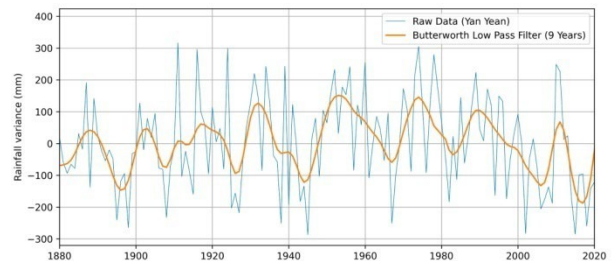
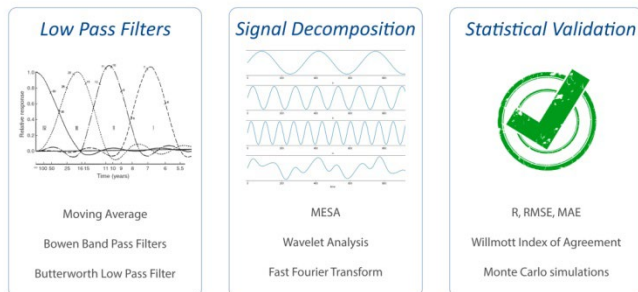


Figure 2: Raw data from Yan Yean weather station (mean centred) and a 9 year low pass filter applied.

## DISCUSSION

An initial literature review supported the presence of decadal lunisolar cycles on precipitation. Barriers to wider acceptance include a perceived lack of rigorous statistical proof. There are significant knowledge gaps which can sufficiently describe or predict the observed amplitude modulation, phase change and regional specificity. Early testing on rainfall by Vines shows great promise for the prediction of drought in Australia, though the theory requires refinement. The development of a long-term predictive model for flood and drought has immense potential for deepening our understanding of the hydrological cycle and benefiting society at large.

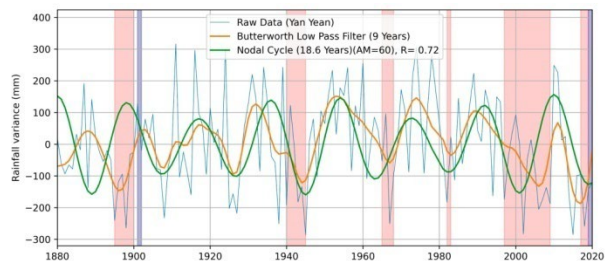
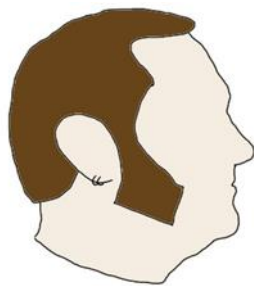


Figure 3: Yan Yean site above with a lunar nodal cycle amplitude modulated by 60 years (green), phase inversion occurring around the year 1900 (purple), and the correlation to major droughts (red).





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**Discipline:** Environmental hydrology

## ABSTRACT

Throughout the world, large regulated waterways downstream of major on-stream dams tend to be the primary focus of environmental water management and ecological conservation efforts. Smaller unregulated waterways tend to be a lower priority focus, or even disregarded entirely. The aim of this research is to better understand and compare the current sources of hydrological stress in smaller waterways, including climate change. Through this research it may be possible to identify areas where climate change impacts could be mitigated through changes to anthropogenic extractions.

## INTRODUCTION

Past research has highlighted the enormous social and ecological value of unregulated streams. However, most studies which examine hydrological threats to biodiversity typically focus on much larger waterways, implicitly assuming that 'smaller' threats in unregulated waterways are less significant. Recent work has highlighted that this is a poor assumption, with a study across the Murray Darling Basin showing that very small dams have a much broader impact than large dams.

Also, studies which have compared sources of hydrological alteration have usually only considered one threat only, or one waterway only. No studies have directly compared the individual effect of a range of threats across a region using a consistent methodology.

## DISCUSSION

For waterway managers, a key piece of knowledge is whether climate change is the dominant threat for a given waterway, or whether there are other threats which may also need to be considered. In each case, the policy and management approach may be significantly different.

Identifying the dominant threats in each waterway is complex, partly because there is no single consistent projection for the impacts of climate change – there are many possible versions of the future (ie. GCMs) with climate change, and all are considered equally likely.

By considering all of the climate change scenarios and all different combinations of threats, several sites have been identified where farm dams and small extractions have a comparable impact to climate change. This is an important finding, as this indicates that managing the consumptive users may help to mitigate the effects of climate change in these locations.

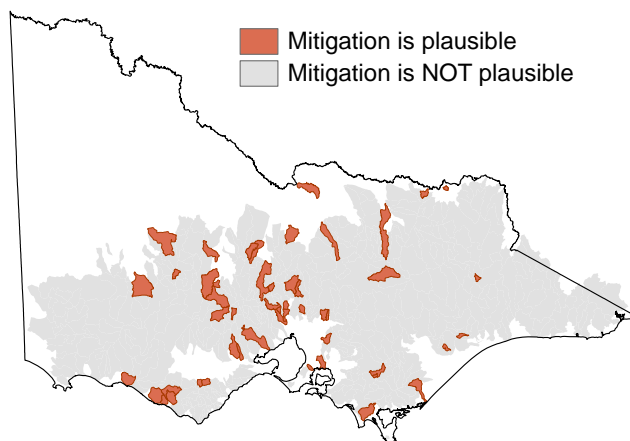
## METHODOLOGY

Using some hydrological modelling outputs from a previous study, a suite of long term stationary flow records representing 'natural' flow (ie. the historic flow if anthropogenic extractions or impoundments had not occurred) was developed for more than 500 sites across the state of Victoria.

Hydrological models were developed to represent the impact of three known major threats to unregulated waterways: climate change, small dams, and small extractions. Each of these models was applied to each waterway separately to understand their individual impacts, and also applied in combination to understand how their impacts might interact.

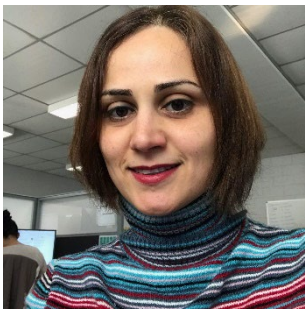
Hydrological indicators (statistics) were used to identify the key differences between threats and the specific ways in which they alter flow regimes.

## FIGURE/DATA



Catchments in Victoria where management of consumptive users in unregulated streams may partly mitigate the impacts of climate change on flows by 2050

# Modelling electrical conductivity with multiple sources of salt in the Scotts Creek, using a Travel Time Distribution Approach



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**Supervisor(s):** Professor Andrew Western  
**Discipline:** Environmental Hydrology and water resources

## ABSTRACT

Concerning modelling water quality, we applied the time tracking method to model electrical conductivity (EC) using the hydrological data in the Scotts\_Creek catchment for 20 years. A time variant StorAge Selection (SAS) function was applied and guided by grouping discharge variations reflecting multiple salt sources in addition to seasonality during modelling EC concentration with an age-based concentration model. Comparing outcomes of alternate scenarios revealed discharge classification regarding EC variations in different seasons is essential to reach a successful model for EC concentration in the Scotts-creek catchment, which highly improves tracking the trend of EC fluctuation and model performance during simulation. Moreover, effect of calibration duration (seasonality pattern in each year) is higher than number of parameters and the implemented models in each configuration.

## INTRODUCTION

Water quality is a crucial and complicated issue that has received greater attention due to frequent drought and imbalance between water demand and its supply. Modelling water quality is a useful device that gives essential insights for catchment management. This research has used time tracking, a lumped method, to model catchment water quality, which estimates travel time distributions of water parcels and their accompanying solutes from their generations to discharge.

## METHODOLOGY

1. Track water balance in water storage for each day.
2. Water travel time distribution (TTD) is calculated for each timestep using streamflow and a storAge selection function (SAS). The SAS is modulated by a) flow or b) flow and catchment wetness. Evapotranspiration is treated in a similar way.
3. Salinity of storage concentration is based on either c) age or d) salt balance.
4. Stream salinity is calculated as flow weighted (from 2) average of storage concentration (from 3).

## DISCUSSION

1. The long EC data has presented a complex pattern of multiple salt sources by reversing EC-discharge correlations in this catchment during each year, which can infer addition of new flow path feeds stream by water with different travel time distributions (TTD) and salinity (Figure 1).
2. Applying time variant SAS function and grouping discharge variations highly improved modelling complex EC concentration in this catchment (Figure 2).
3. The resulted TTD and RTD for selected dates in different seasons along a year could present trace of arriving different flow paths started feeding the stream by seasonal changes (Figure 3).

## FIGURE/DATA

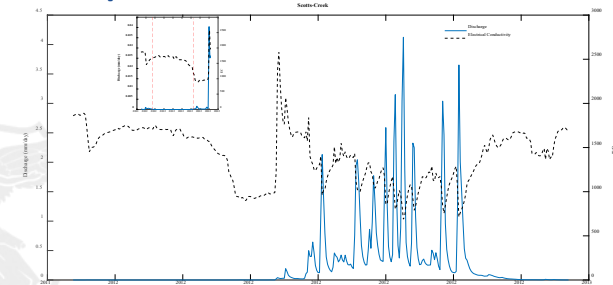


Figure 1: Discharge and electrical conductivity timeseries in the Scotts-Creek catchments in 2012. Different sections with specific pattern of EC regarding discharge variations (recognizable in all years) are separated by red lines.

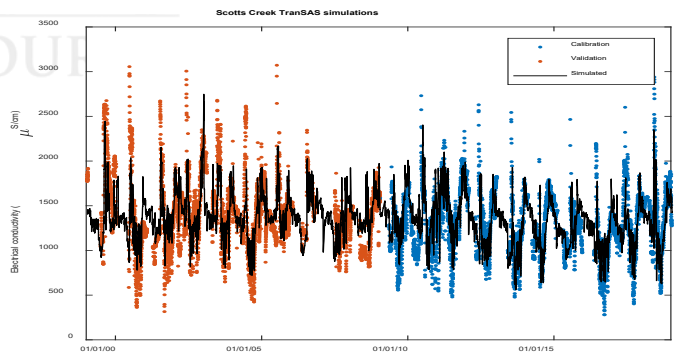


Figure 2: Timeseries of observation and simulated EC data during two calibration (blue dots) and validations (red dots)

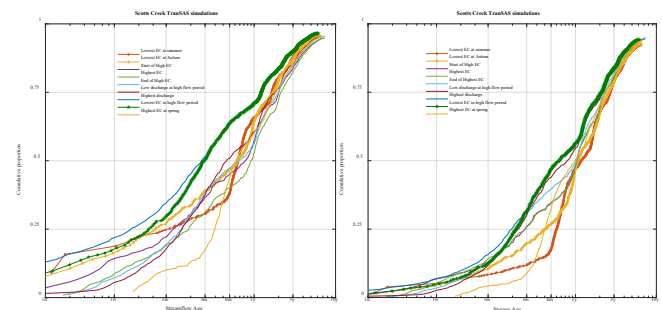
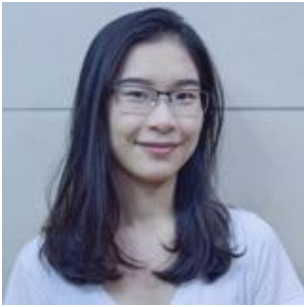


Figure 3: Average of TTD and RTD in the selected dates for all 20 years (1999-2018).





# Post-processing of NWP forecasts using reanalysis data and station data

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**Supervisor(s):** Prof. Quan J. Wang, Dr. Wenyan Wu  
**Discipline:** Environmental Hydrology and Water Resources

## ABSTRACT

Statistical post-processing of forecasts from numerical weather prediction (NWP) models aims to correct systematic bias, convey reliable forecast uncertainty and make post-processed forecasts approach to climatology forecasts when NWP forecast skill is low. A post-processing method is developed by identifying discrepancies between historical forecasts and associated observations. However, it is challenging when historical observations are lack. This study provides guidance on the use of gridded reanalysis data and accurate station data for weather forecast post-processing. NWP precipitation forecasts post-processed by following the guidance are evaluated at 50 locations in different climate zones in Australia. Results show that the post-processed forecasts are as skillful as when observations are available to develop the same post-processing method.

## INTRODUCTION

Weather forecasts are routinely issued by using NWP models. Due to chaotic climate, statistical post-processing of NWP model outputs is necessary for improving forecast. Establishment of post-processing method requires sufficient archived forecast data and observed data. A seasonally coherent calibration (SCC) model successfully overcomes difficulties in working with limited archived NWP data. But long-term observed data is still required. This study provides guidance on the use of gridded reanalysis data and accurate station data for establishing the SCC model.

## METHODOLOGY

SCC model is based on a joint probability model of forecast data and observe data. To replace the use of observed data, other two sources of data are considered:

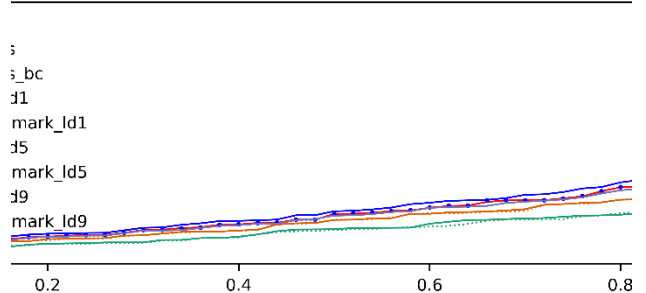
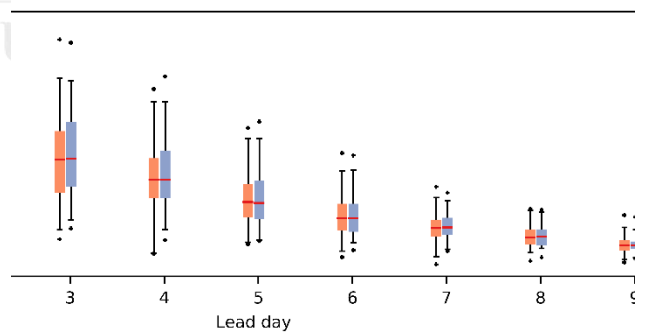
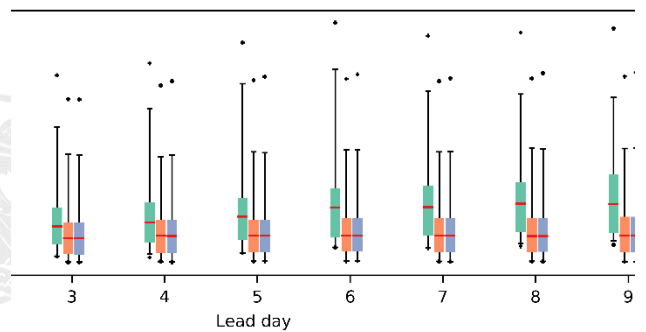
1. BARRA reanalysis data that is produced in a spatially and temporally consistent way. BARRA after bias correction is used to derive observed climatology.
2. Accurate daily station data is used to estimate the coefficients between the model climatology and observed climatology. The coefficient values at a gauged location is transferred to surrounding forecast locations based on defined criteria.

## DISCUSSION

With use of BARRA data and station data, the established SCC model lead to post-processing performance as strong as using direct observations for establishment. The strong performance is manifested as having lower MAE than raw NWP forecasts, CRPS skill scores and twCRPS skill scores as high as the benchmark SCC.

BARRA is a useful dataset to provide climatological information. Bias-corrected BARRA can lead to accurate climatology estimates that is consistent with observations. Whether this guidance can be applied to post-process ensemble NWP forecasts needs to be further investigated.

## FIGURE/DATA





# Development of fast and accurate hybrid model for floodplain inundation simulations

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**Supervisor(s):** QJ Wang, Wenyan Wu and Rory Nathan  
**Discipline:** Environmental Hydrology and Water Resources

## ABSTRACT

High computational cost is often the most limiting factor when running high-resolution hydrodynamic models to simulate spatial-temporal flood inundation behaviour. To address this issue, this study develops the hybrid Low-fidelity, Spatial analysis, and Gaussian Process learning (LSG) model. The LSG model simulates the dynamic behaviour of flood inundation by upskilling simulations from a low-resolution hydrodynamic model through Empirical Orthogonal Function (EOF) analysis and Sparse Gaussian Process (Sparse GP) learning. The LSG model is evaluated on the Chowilla floodplain in Australia and accurately predicts flood inundation while being significantly more computationally efficient than a high-resolution hydrodynamic model.

## INTRODUCTION

Each year, flooding causes massive destruction of infrastructure and loss of lives all around the world. Flood inundation is traditionally modelled using high-resolution hydrodynamic models that simulate the physical processes of flooding. However, due to the degree of detail needed (high-fidelity), the computational costs are often too high for practical purposes. This study, therefore, develops a computationally efficient hybrid model that uses a low-fidelity model, Spatial analysis and Gaussian Process learning (i.e. LSG model) to make predictions.

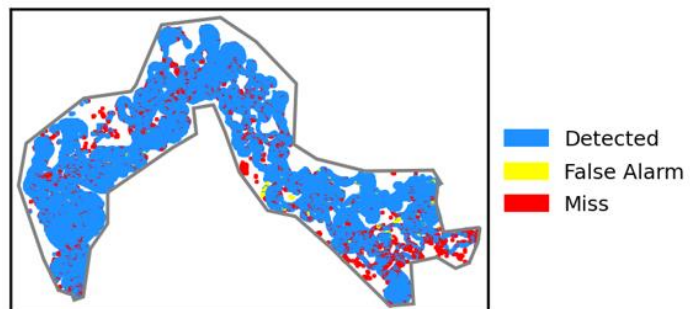
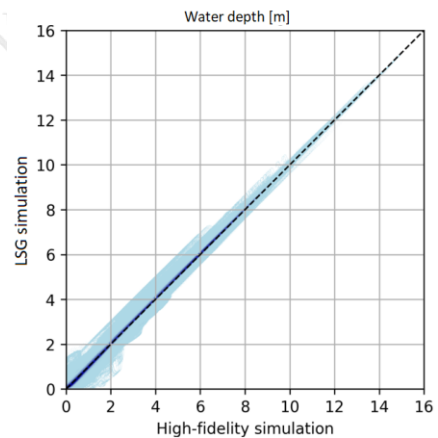
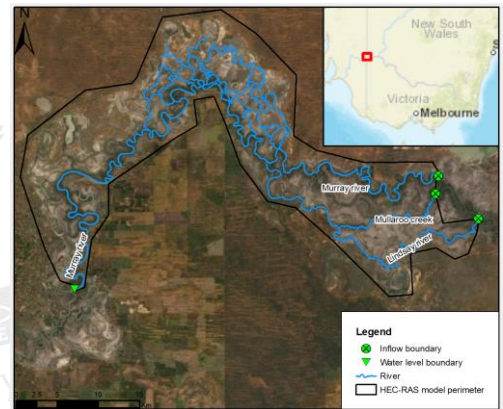
## METHODOLOGY

The LSG model first uses a low-fidelity model to simulate flood inundation on a coarsely discretised grid. Due to the coarse resolution of the low-fidelity model, the simulation time is significantly faster than using a high-fidelity model, but the accuracy is also reduced. The low-fidelity predictions are, therefore, upskilled by first applying Empirical Orthogonal Function (EOF) analysis to reduce the dimensionality of the low-fidelity data to a few key features and secondly, using a Sparse Gaussian Process (Sparse GP) model to convert the key low-fidelity features to high-fidelity features.

## DISCUSSION

This study demonstrates that the LSG model is a powerful tool to upskill low-fidelity model simulations to emulate the results of a fully 2D hydrodynamic high-fidelity model. The LSG model predicts water depths with a mean RMSE of 6 cm and a standard deviation of 7 cm, thereby making it a powerful tool for risk assessments. However, the methodology needs to be tested on other types of flooding behaviour and study sites to ensure that the prediction accuracy of the LSG model is robust. In addition, a methodology for the creation of the low-fidelity model to ensure both the accuracy and computational efficiency of the LSG model needs to be developed.

## FIGURE/DATA





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# CIVIL ENGINEERING STREAMS

- GEOTECHNICAL ENGINEERING
- OCEAN ENGINEERING
- STRUCTURAL ENGINEERING
- TRANSPORT
- ENGINEERING MANAGEMENT & ENERGY





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# GEOTECHNICAL ENGINEERING





# Modified DEM Replacement Method for Rockfill Modelling



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**Discipline:** Geotechnical Engineering

## ABSTRACT

Rockfill, a granular material with particle sizes usually in the range of 2 cm to 1 m, is commonly used as the main construction material in a range of civil engineering applications such as water and tailings retaining embankment dams. The investigation of mechanical behaviour of rockfill requires expensive and time-consuming laboratory testing in large apparatuses, which are scarce. This highlights the importance of numerical investigation techniques such as Discrete Element Method (DEM) in better understanding of rockfill properties. In this research, Modified Replacement Method which is a combination of Replacement and Bonded-Particles (clusters) methods is proposed so the effects of particle shape and breakage, which are among the most effective parameters, can be adequately investigated.

## INTRODUCTION

Common use of rockfill in geotechnical structures and mining applications on one hand, and its complex behaviour, on the other hand, highlight the need for further investigations. The complex mechanical behaviour of rockfill mainly stems from its inherently discrete and heterogeneous nature. Considering large dimensions of rockfill particles, the current design practice and understanding of its mechanical behaviour heavily relies on either correlations established from limited number of historical experimental data or testing of samples with reduced particle sizes.

## METHODOLOGY

To lay foundations for studying and analysing the behaviour of rockfill material, a framework using DEM is established based on the Modified Replacement Method. To investigate the effect of particle's characteristic strength (23.22 MPa, 43.18 MPa and 350.7 MPa assigned to the Weak, Medium, and Strong particles, respectively), breakage, and confining stress on the mechanical behaviour of rockfill assemblies, 3D triaxial tests conducted using ITASCA PFC3D. Finally, the effect of these parameters on the shear strength, volumetric deformation, and critical state parameters are analysed.

## DISCUSSION

Illustration of broken particles showed a well capture of concentration of critical daughter particles at the shear band zones that were inconsistent with the displacement of mother particles and the particle translation gradient concept. The dilative behaviour of strong particles moved toward compaction due to particle breakage. Instabilities imposed to the assemblies resulted from breakage throughout the BCS shifted to the more stable zone after the critical confining stress for the breakable particles' assemblies. Besides, major of bonds between the sub-particles of daughter particles were broken in tension at low axial shearing strain under relatively low confining stresses.

## FIGURE/DATA

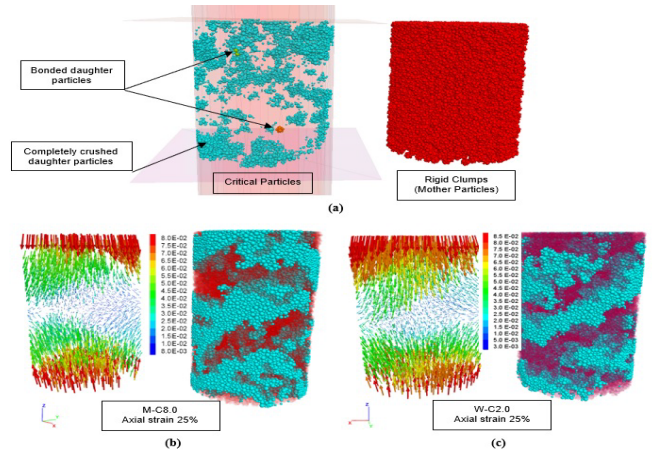
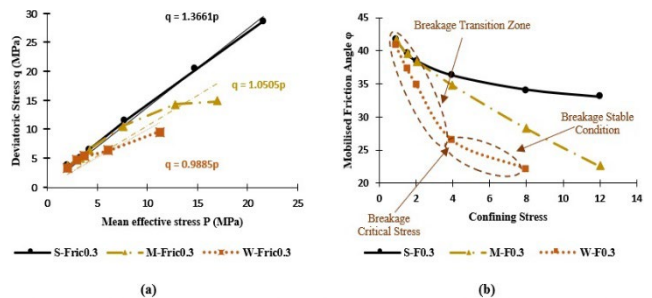
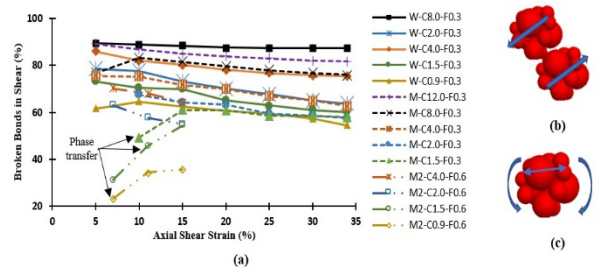


Illustration Critical particles and Micro parameters: a) Rigid Mother particles and critical broken daughter particles at axial shearing strain of 35% for the weak particles under 0.8 MPa confining stress; b) Displacement contours for clumps and demonstration of broken particles concentrated at shear band zone at axial shearing strain of 25% for the medium particles under 8.0 MPa confining stress; c) the weak particles under 2.0 MPa confining stress.



Assemblies' peak strength parameters: a) peak deviatoric stress versus mean effective stress, & b) Inter-particles mobilised friction angle variation in different confining stresses for particles with different characteristic strength.



Status of broken bonds of clusters in different assemblies: a) Bonds broken in shear at different axial strains for different confining stresses, particle's characteristic strength, and friction angles; b) Shearing induced breakage in relatively loose assemblies; c) Bending-induced tension breakage in extremely compacted assemblies.





# Thermal properties enhancement of backfill materials comprised of phase change materials, graphite and glass

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**Discipline:** Geotechnical Engineering

## ABSTRACT

Phase change materials (PCM) can store / release heat energy at a constant temperature. Using them for backfill materials can improve the ground thermal density. However, PCM will reduce the heat transfer in backfill materials because of its relatively low thermal conductivity. Thus, other additives need to be added for the effective thermal conductivity enhancement and then corresponding geothermal systems efficiency. This study incorporates encapsulated PCM (EPCM) and graphite into glass fines with the purpose of using the mixtures as backfill materials. Then the thermal properties (heat capacity and thermal conductivity) of mixtures with different content of EPCM and graphite are measured. The experimental data agree with the theoretical mixture model values. The results indicate the amount of EPCM and graphite has a great influence on the thermal properties of mixtures.

## INTRODUCTION

PCM can store / release heat at constant temperature. Using them for backfill materials can improve the ground thermal density. However, PCM will decrease the heat transfer because of its relatively low thermal conductivity. Thus, other additives need to be added for the effective thermal conductivity enhancement. This study adds encapsulated PCM and graphite to glass fines and aims to use the mixtures as backfill materials. The thermal properties of the mixtures with different EPCM, graphite and glass fine volume percentage are measured. Then the experimental data are compared with the predicted values.

## METHODOLOGY

- Containers of 70 ml are used to create the samples of mixtures. Each sample has a controlled components content and a unified porosity of 0.47.
- An environmental chamber is used to keep the samples at 4 °C or 45 °C during measurements, considering EPCM is in solid / liquid phase at 4 °C / 45 °C.
- Decagon KD2 Pro thermal analyser with a dual thermal needle is adopted for measuring the thermal conductivity and heat capacity.
- The geometrical mean model is employed to calculate the theoretical thermal property values.

## DISCUSSION

- Thermal conductivity increases with graphite volume percentage while decreases with EPCM content. The temperature influence on thermal conductivity is limited.
- Heat capacity rises with EPCM volume percentage but drops with graphite content, and it is higher under 45 °C than 4 °C.
- Thermal diffusivity declines with EPCM volume percentage but grows with graphite content. It is higher at 4 °C, which indicates the mixtures have faster thermal response to the change of surrounding temperature when EPCM is under solid phase.

## FIGURE/DATA



Fig. 1 Materials used for backfilling

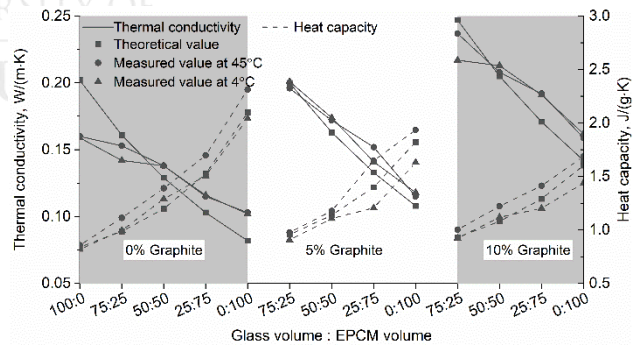


Fig. 2 Thermal conductivity & heat capacity: measured vs predicted

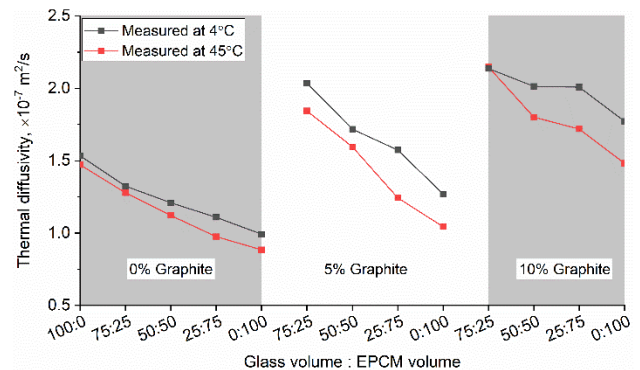


Fig. 3 Thermal diffusivity: measured vs predicted





# Thermal performance of energy tunnels: The impact of groundwater and tunnel airflow

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**Discipline:** Geotechnical Engineering

## ABSTRACT

An innovative technology integrating underground tunnels with the function of ground heat exchangers (GHEs), called energy tunnels, has gained increasing attention in energy geotechnics research. In this study, a 3D transient thermo-hydraulic numerical model is developed to explore the coupled effects of groundwater and tunnel airflow on the energy tunnel system. Results show that even for limited airflow and groundwater flow parallel to the tunnel longitudinal axis, while the total thermal yield significantly increases with respect to a non-groundwater flow situation, the associated heat convection can cause substantial thermal interference downstream of the tunnel, thus affecting the fluid temperature among each GHE loop and the heat pump's working efficiency.

## INTRODUCTION

Compared to borehole GHEs, energy tunnels may exchange heat not only with the surrounding ground but also with internal air space. Numerical and experimental studies have shown that the groundwater and tunnel airflow can respectively affect the carrier fluid temperature and the energy tunnel's overall thermal performance. The groundwater flow and tunnel airflow can both be present and concurrently influence the temperature field and the heat transfer behaviour of energy tunnel system. However, their coupled effects is hardly investigated in the literature, which is the aim of this work.

## METHODOLOGY

A 3D coupled thermo-hydraulic transient energy tunnel numerical model that incorporates both groundwater flow and the tunnel airflow is developed in the FEM package COMSOL Multiphysics and validated against published experimental data.

The non-isothermal tunnel airflow is fully simulated to capture the air temperature variations during heat exchange. The model was then applied to investigate the coupled effects of different groundwater flow and tunnel airflow conditions (e.g., velocities and directions) on the thermal performance of energy tunnels.

## DISCUSSION

The carrier fluid temperature is oscillating periodically with the air temperature profile, and its amplitude strongly depends on the airflow velocities. When the airflow is less than 0.05 m/s, the entering water temperature (EWT) for parallel groundwater flow is about 17% to 25% higher than that of perpendicular groundwater flow, which leads to a 7% to 17% decrease in coefficient of performance (COP) of the heat pump. This work also highlights the necessity of a detailed 3-D numerical modelling to assess the thermal yield of long thermally activated tunnels when dealing with parallel groundwater flow and its importance in energy tunnel geothermal design.

## FIGURE/DATA

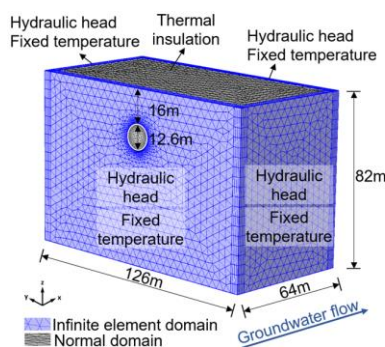


Fig.1 Main geometry, mesh and boundary conditions of the numerical model

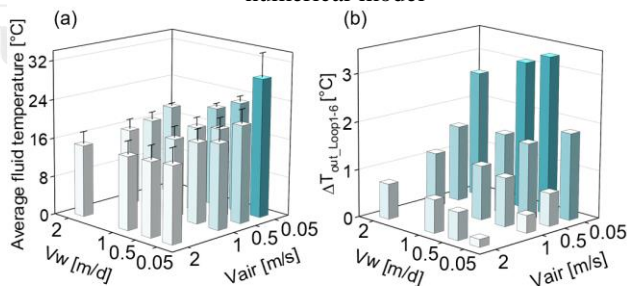


Fig.2 Average fluid temperature (a), and difference in outlet temperature between Loop 1 and 6 (b).

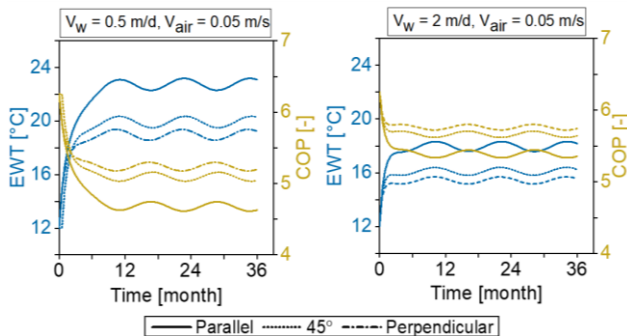


Fig.3 EWT and corresponding COP for different groundwater flow velocities and directions when airflow is 0.05 m/s.



# Behaviour of Battered Mini Pile System Subject to Complex Loading in Cohesive Soil



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**Discipline:** Geotechnical Engineering

## ABSTRACT

Battered mini pile systems are hybrid foundation systems supporting small to medium-scale structures onshore and shallow offshore. These systems resist a complex load regime consisting of vertical and cyclic lateral loads. This study investigates the lateral performance of the systems in terms of pile-soil-pile interaction and interaction between loads in cohesive soil. Physical model tests using a centrifuge and advanced numerical modelling will be carried out to address the research questions. This study systematically investigates the battered mini pile system's behaviour under static complex loads and investigates the system's behaviour under cyclic complex loads.

## INTRODUCTION

Battered mini pile systems are hybrid foundation systems. They are cost-effective foundations, can be installed quickly, even in places with limited access, and leave less carbon footprint. They have been used to support various small to medium-scale structures and, most importantly, renewable energy structures onshore and shallow offshore. Vertical loads and cyclic lateral loads (due to wind and waves) are imposed on these systems. In this study, the behaviour of the battered mini pile system under complex loading in cohesive soil is investigated.

## METHODOLOGY

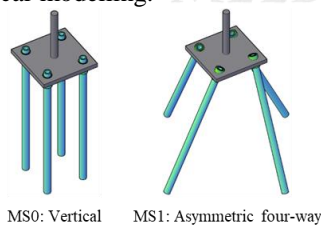
The study is being carried out using physical model tests using a centrifuge and numerical modelling.

Centrifuge test regime:

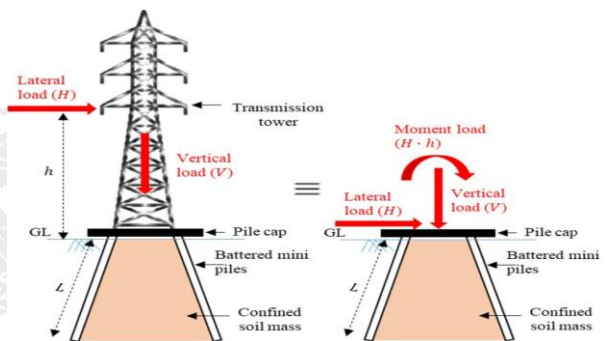
- Single battered mini piles
- Two types of systems

Numerical modelling:

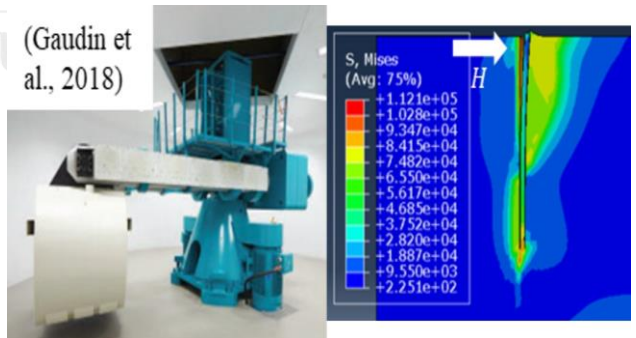
- ABAQUS/CAE
- Soil constitutive models:
  - Tresca
  - Clay hypoplasticity
- Interface: Coulomb friction, Cohesive



## FIGURE/DATA

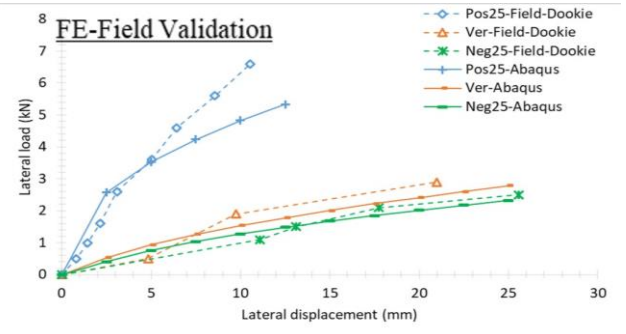
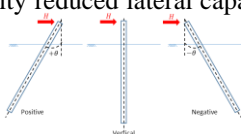


(Gaudin et al., 2018)



## DISCUSSION

- Positive 30° mini pile showed the highest lateral capacity.
- Lateral capacity increased with batter angle for positive mini piles due to the large passive wedge, whereas batter angle did not influence the capacity of negative mini piles in clay.
- Lateral capacity increased with penetration length
- Load eccentricity reduced lateral capacity significantly.





# Investigation of helical piles installation and the impacts on holding capacity

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**Discipline:** Geotechnical Engineering

## ABSTRACT

This research aims to firstly understand the processes occurring during the installation in both experimental and numerical ways, in order to develop a comprehensive framework to predict the installation resistance under different advancement ratio. Then, the behavior of helical piles under combined loading will be fully investigated, accounting for the soil disturbance generated during installation from the first step. Finally, the comparison of the holding capacity between “wished-in-place” and “post-installation” conditions will be analyzed to provide a design guidance for helical piles.

## INTRODUCTION

Nowadays, helical piles have been widely applied for land use especially for light weight structure, such as transmission tower. However, there is very few discussions of their application for offshore engineering in recent years, even though they are deemed to be useful for offshore geotechnical engineering. Due to the difference of load forms and load scales between onshore and offshore, significant challenges remain before helical piles can be used in the offshore renewable energy industry.

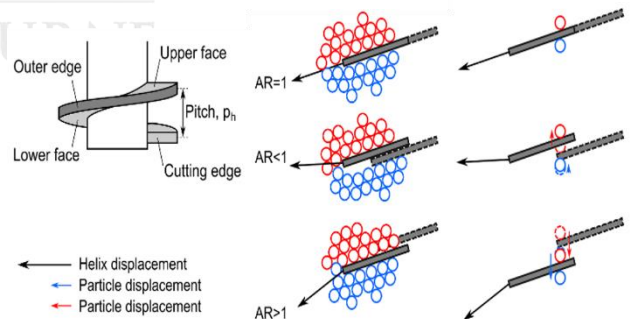
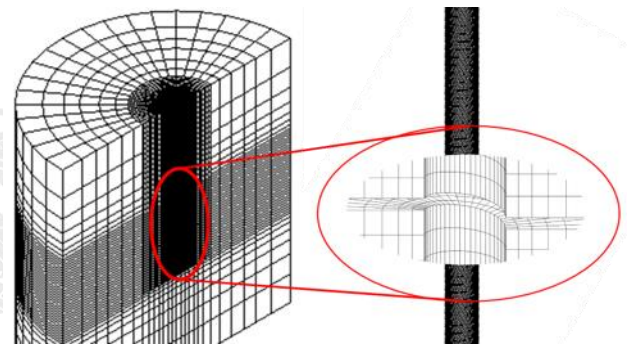
## METHODOLOGY

1. Numerical simulation
  - 1.1 3D large deformation numerical analysis
  - 1.2 Small strain analysis
2. Physical modelling
  - 2.1 Centrifuge tests
  - 2.2 1-g tests

## DISCUSSION

The present study expects to develop the scientific breakthroughs and lay a basis for the application of helical piles as foundations for the offshore wind turbines. Large deformation numerical model will ensure that the installation requirements of helical piles can be accurately predicted, which will be validated by the centrifuge tests results. Also, both the centrifuge tests and small strain analysis will capture the soil disturbance during the installation to understand the impacts on the subsequent pull-out behavior. The outcomes of this study will be able to provide reliable design guidelines for the application of helical pile to the offshore wind industry.

## FIGURE/DATA





# Geotechnical Behaviour of Anchor Chains and Integrated Mooring Line Analysis

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## ABSTRACT

Offshore floating facilities are required to be secured through a mooring system, which comprises anchors and mooring lines. Research on embedded segment of mooring line is confined to two-dimensional analysis. Friction and normal soil resistance to embedded anchor chains are calculated using empirical parameters in the existing chain solutions. Existing solutions on anchors and mooring line segments in soil and water are not coupled. The aim of this research is to gain in-depth knowledge about the soil resistance to the chain links, advance the fundamental understanding of three-dimensional performance of the embedded anchor line and develop for three-dimensional analysis of mooring lines and anchors. An integrated system model

## INTRODUCTION

Embedded anchor line forms an inverse catenary configuration in seabed due to normal soil resistance. In existing analytical and numerical approaches, the uncoupled characteristic of soil resistances to anchor chains can lead to inaccurate estimation of anchor line configuration. Moreover, the embedded anchor, anchor line in soil and mooring line segment in water have been not considered as a whole system for analysis. Thus, it is necessary to develop an integrated model for coupled analysis of mooring system components.

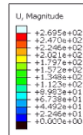
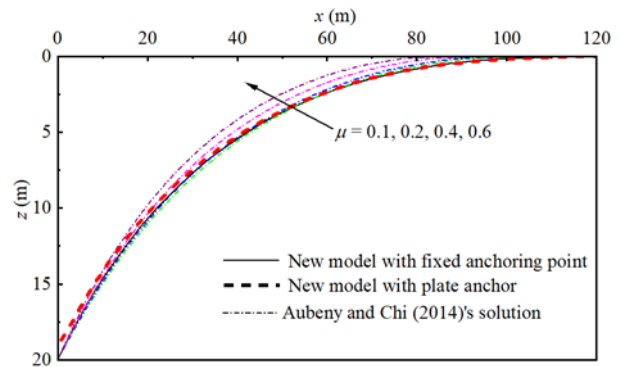
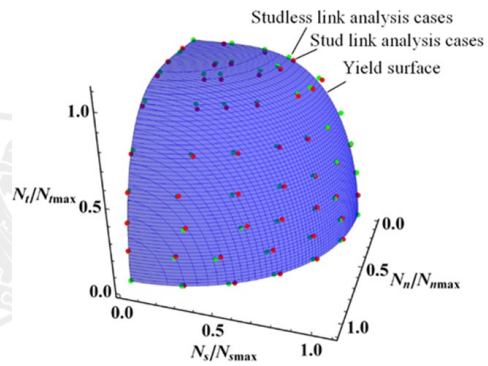
## METHODOLOGY

Finite element modelling method is used to investigate soil resistance to anchor chains. An elasto-plastic macroelement model is developed to define the soil resistance to anchor chains. An anchor line model based on the macroelement models is proposed to model the embedded mooring line in three-dimensional space. An integrated system model is developed for hydrodynamic analysis of mooring lines.

## DISCUSSION

The shapes of yield surfaces for stud and studless link chains are approximately the same for the same embedment depth. Fixed friction coefficients used in the existing analytical method can result in inaccurate chain solution. Three-dimensional performance of a mooring line can be predicted by the integrated system model.

## FIGURE/DATA



Step: Dynamic  
Increment: 0; Step Time = 0.000  
Primary Var: U, Magnitude  
Deformed Var: U, Deformation Scale Factor: +1.000e+00





# Supporting Decision-makers for Prioritising Urban Green Spaces in Resource Constrained Scenarios.

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## ABSTRACT

Greening cities is of considerable significance in creating sustainable cities. However, maintaining this urban green is often challenging due to changing climatic conditions, shortage of staff, inadequate funding, and lack of expertise. Accordingly, city managers struggle to find the right balance between conflicting objectives and taking informed decisions. To address this gap, an optimisation model was developed based on a goal programming approach to allocating the limited resources such that benefits are maximised while satisfying the resource constraints. The developed model is applied in a case study of a metropolis and the results are demonstrated to prioritise those parks that could achieve the maximum benefit with the available resources.



## INTRODUCTION

Cities often encounter stress between a desire to increase urban green spaces (UGS) and the use of limited resources to maintain them. Multi-criteria decision-making methods can help in taking rational decisions in case of conflicting criteria. From numerous available approaches, goal programming was chosen due to its capability to handle multiple goals simultaneously. It is based on the principle of minimizing the underachievement of each goal with the help of deviation variables. The parameters used in the model are as follows:

$G$ = Set of urban green spaces	$B^{access}$ = Access benefit goal
$G_p$ = Set of prioritized spaces	$B^{quality}$ = Quality benefit goal
$w_i^{demand}$ = Water demand of unit $i$	$ra_i$ = Resource allocation decision
$p_i^{demand}$ = Personnel demand of unit $i$	$d1$ = Deviation from access goal
$W^{available}$ = Total water available	$d2$ = Deviation from quality goal
$p^{available}$ = Total personnel available	$w1$ = Weight for access goal
$b_i^{access}$ = Access benefit of unit $i$	$w2$ = Weight for quality goal
$b_i^{quality}$ = Quality benefit of unit $i$	$D$ = Total deviation for all goals

## DISCUSSION

The developed model allocates limited resources, water, and personnel such that the accessibility and quality benefits that are obtained from the UGS are maximised. The figure below demonstrates how resource allocation will happen for case-study city (Berlin) in (i) prioritising based on benefits and (ii) prioritising in case of resource-constraint. The green markers represent the UGS that are prioritised for allocating resources. It is important to highlight that the goal programming method derives a solution that satisfies the goal rather than optimising. Therefore, some resources might remain unused for the final solution condition. Moreover, the model can be further extended to include temporal and spatial goals and constraints as well as additional benefits and management demands to obtain more realistic trade-off scenarios. The method is reproducible for any part of the world depending on the availability of the open datasets.

## METHODOLOGY

Goal-programming based optimisation model:  
**Minimize,**

$$D = \sum_{i \in G_p} w1 * \frac{d1}{B^{access}} + w2 * \frac{d2}{B^{quality}}$$

s.t.

$$\sum_{i \in G_p} b_i^{access} + d1 = B^{access} \quad \text{Soft constraints (Goals/Benefits)}$$

$$\sum_{i \in G_p} b_i^{quality} + d2 = B^{quality}$$

$$\sum_{i \in G_p} w_i^{demand} \leq W^{available} \quad \text{Hard constraints (Resource/Cost)}$$

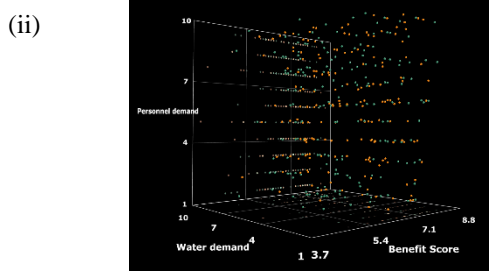
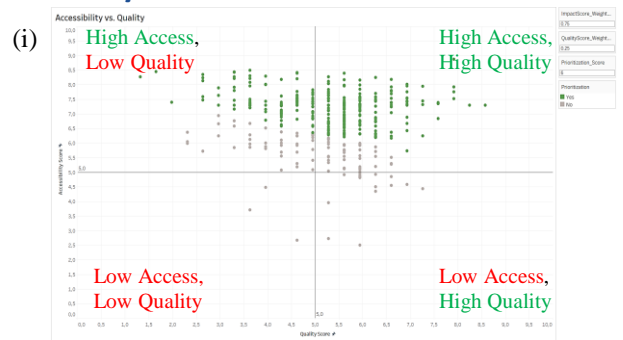
$$\sum_{i \in G_p} p_i^{demand} \leq p^{available}$$

$$g_p = ra_i * G \quad \forall i \in I$$

$$ra_i \in (0,1) \quad \forall i \in I$$

The model was implemented in Python language and was solved using the CP-SAT solver available as a part of Google OR tools library for constraint optimisation.

## FIGURE/DATA





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**Discipline:** Geotechnical Engineering

## ABSTRACT

Pipeline walking has been emerged as a challenge for offshore geotechnical engineers. Pipeline walking is a ratcheting phenomenon which over a number of cycles lead to very large global axial displacement with associated overload of the spool piece or jumper. Pipeline walking is mainly governed by axial pipe-soil interaction. The present research aims to study the pipe-soil axial interaction systematically. Analytical work will be carried out to study the effect of subsea manifold reaction and change in SCR tension on walking rate. Whereas various aspect of axial pipe-soil interaction will be looked into by numerical simulation (Abaqus UEL) and physical modelling (1g test).

## INTRODUCTION

Subsea pipelines are increasingly being required to operate at high temperatures and pressures. Pipelines operating at high temperature have a high propensity to Euler (column-type) global buckling. It is usual for lateral buckling to occur at lower axial force than vertical buckling, unless the pipeline is trenched or buried. Pipeline walking has also been emerged as a challenge which is a phenomenon in which start-up/shut-down cycles cause a ratcheting response in the pipeline axial displacement. Over a number of cycles this ratcheting can lead to very large global axial displacement.

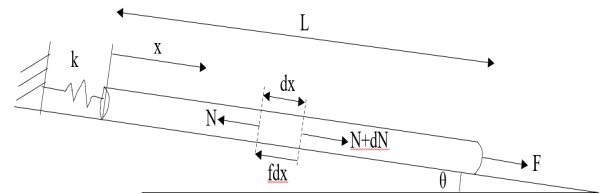
## METHODOLOGY

- Analytical framework .
- Reaction from subsea manifold has been simulated by a linearly elastic spring.
- Pipe-soil interaction has been modelled as rigid plastic.

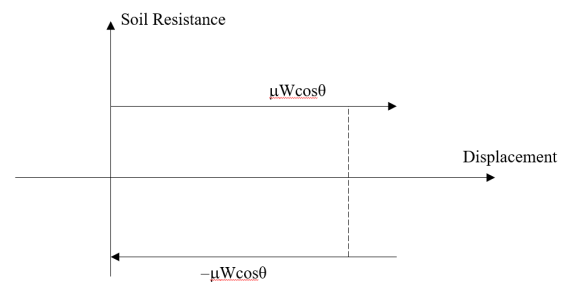
## DISCUSSION

The present study shows that there is significant influence of subsea manifold system on walking rate. Though for initial cycles walking rate is more compare to free ended scenario, eventually as the heating up-cooling down cycle goes on walking rate will gradually decrease and eventually ceased. Hence, for accurate estimation of walking, reaction from subsea manifold system needs to be taken into account.

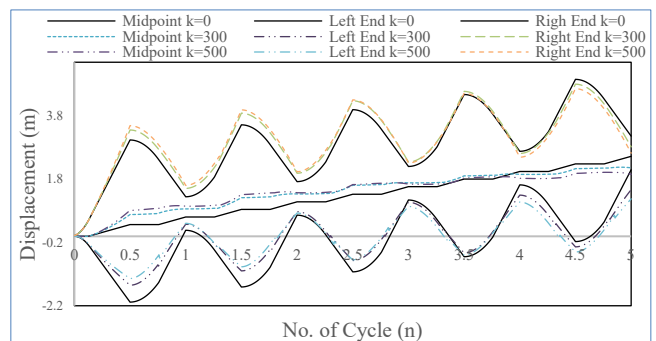
## FIGURE/DATA



Pipeline calculation model and sign convention



Rigid plastic model for soil resistance



Displacement history of the pipeline







# Impact of Specimen Preparation on Erosion and Post-Erosion Response of Gap-Graded Soils

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## ABSTRACT

Internal erosion is a major threat to the safety of earthen structures and occurs in four different forms: suffusion, concentrated leak, backward erosion, and contact erosion. Suffusion is defined as the selective erosion of non-plastic fine particles through the pore network formed by the coarse particles under seepage flow. Despite recent enhancements in understanding suffusion's influence on the mechanical behaviour of internally unstable soils, the impact of different sample preparation methods is yet unclear. This study aims to provide insight into the influence of specimen preparation techniques on the erosion of fine particles in internally unstable soils and their mechanical consequences.

## INTRODUCTION

The soil specimens prepared by various techniques have different soil fabrics and hence, distinct characteristics. While several studies have investigated the impact of sample preparation on the mechanical behaviour of soils, the literature review shows a lack of knowledge about how it affects the erodibility of fine particles in internally unstable soils. In this study, two distinct methods are employed to consider the effect of different specimen reconstitution techniques on the erodibility of internally unstable soils and their mechanical consequences.

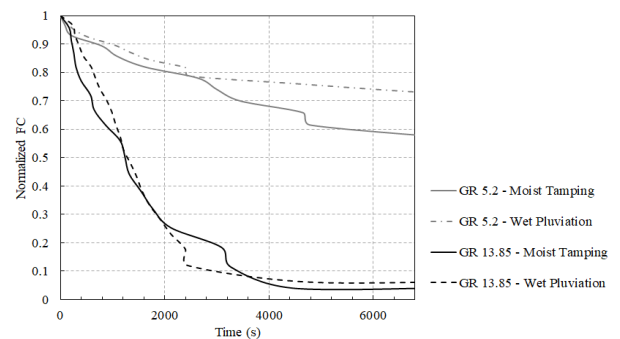
## METHODOLOGY

To prepare samples with 75mm in diameter and 150mm in height, moist tamping, and wet pluviation techniques were implemented. Two different gap ratios (5.2 and 13.85) were selected, one as a representative of the samples on the borderline of stable and unstable and the other one as fully unstable. A customized triaxial erosion apparatus accompanied by a water supply system and collection tank was used to investigate the initiation and development of internal erosion. The erosion phase started after consolidation and continued for two hours.

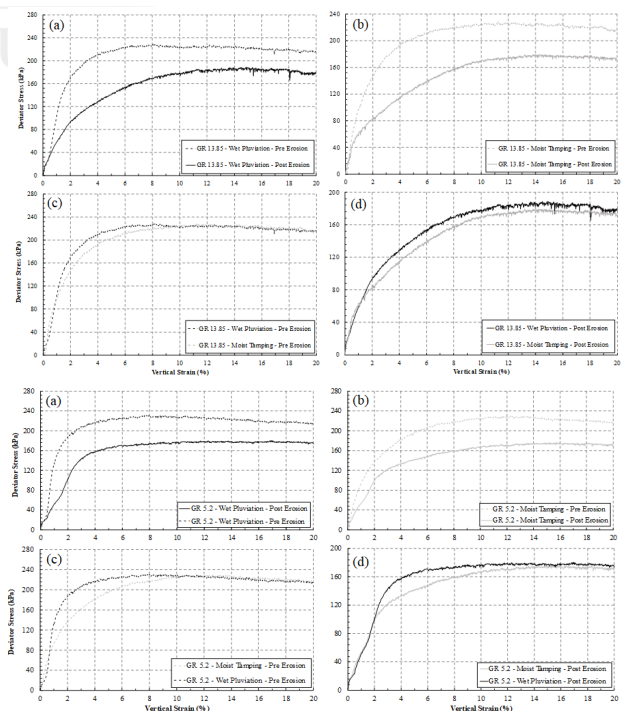
## DISCUSSION

The amount of erosion for the gap ratio of 13.85 was almost the same for both methods of sample preparation. However, the same analysis gives varied results for the 5.2 gap ratio in terms of erodibility. Surprisingly, samples prepared by different techniques show similar stress-strain behaviour regardless of the amount of erosion. This could be because of the difference between the pore networks constructed in these two sample preparations. In another word, in the gap ratio of 5.2, some of the fine particles are not contributing to the soil stress matrix. It means that they cannot pass through the voids, accordingly resulting in different erodibility and similar mechanical behaviour.

## FIGURE/DATA



Real time normalised residual fine content variation.



Impact of different sample preparation on the drained stress-strain relationship.





# Impact of particle shape on permeability of granular materials based on LBM-DEM and pore network analysis

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## ABSTRACT

The hydraulic properties of granular materials are of great importance in engineering applications, while the influence of particle shape on them has not been fully studied. This research bridges this gap with an advanced workflow that combines image processing, Lattice Boltzmann Method (LBM), non-spherical discrete element method (DEM) and complex network theory. Geometries of five natural sand particles with distinct shapes are extracted from micro Computerized Tomography images. Then, monodisperse granular assemblies of different particle shapes and overall porosities are generated. The pore fluid flow pattern is unveiled using LBM and pore networks are constructed to characterize pore structures. The results show the particle shape has a significant impact on pore structures and thus on the fluid flow, permeability, and tortuosity.

## INTRODUCTION

The hydraulic properties of porous media are of great importance in engineering applications such as geothermal and geotechnical engineering and such properties are fundamentally influenced by its microstructures. Links between particle shape and the hydraulic properties of the granular material, for example are largely unknown. Here the micro-geometries of five natural sand particles are obtained from CT scanning and used to study such relationships in non-spherical particle assemblies. Lattice Boltzmann & Discrete Element Methods (LBM-DEM) are used in one of the first studies of its kind here.

## METHODOLOGY

This research is conducted based on non-spherical LBM-DEM models that simulate the fluid flow in monodisperse granular assemblies with different realistic particle shapes and porosity. First, assemblies are prepared in a confining box. Then, a hydraulic gradient is prescribed to drive the fluid flow and reveal the hydraulic properties. In parallel, pore network models are constructed using maximal inscribed spheres to determine the tortuosity and statistical distribution of the pore structures; and fluid fields from the LBM simulation are statistically analysed and related to this characterization of the pore structures.

## DISCUSSION

- Particle shape and porosity could influence the local fluid flow behaviour and thus change the statistical distribution of fluid velocity.
- The particle shape could significantly influence the pore network structures. The statistical distribution of both pore and throat shows double peaks. The more rounded particles generally tend to have larger pores.
- The permeability and tortuosity of the assemblies are influenced by the particle shape parameter sphericity. As the irregularity of particles increases, the fluid flow path becomes more distorted.

## FIGURE/DATA

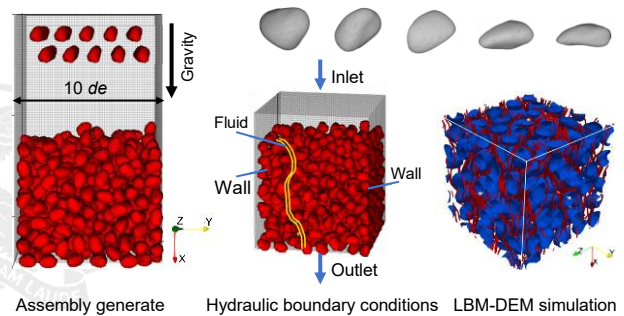


Fig.1 DEM-LBM numerical model

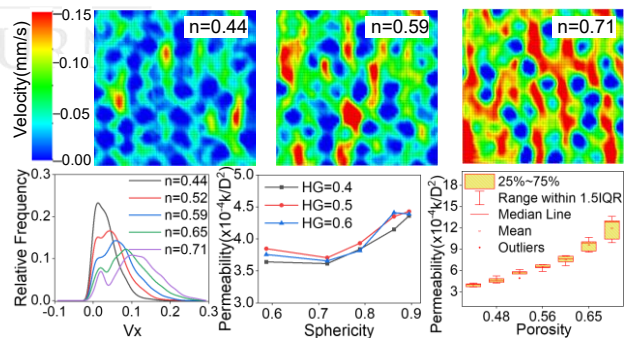


Fig.2 Fluid flow analysis

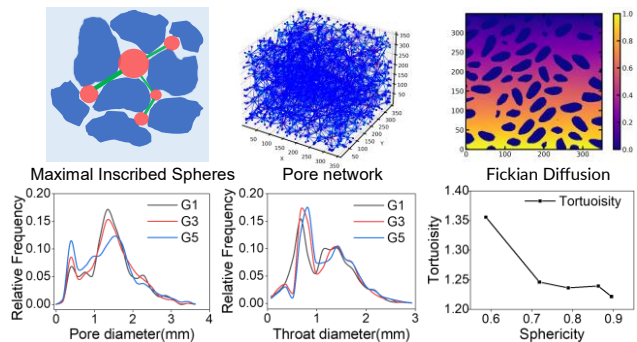


Fig.3 Network analysis





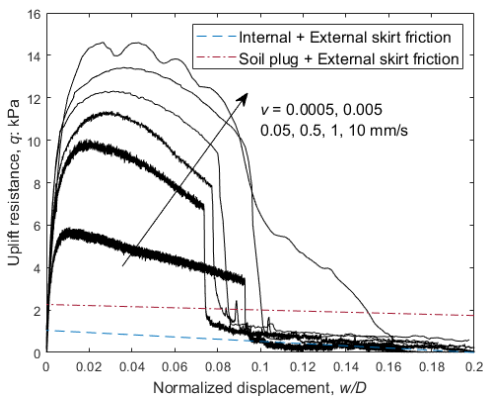
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**Discipline:** Geotechnical Engineering

## ABSTRACT

Most of us have experienced the difficulty of lifting our shoes up from muddy ground (the quintessential ‘stuck in the mud’). This tells us that uplifting an object off the seabed requires much greater than its own submerged weight. This is termed as breakout phenomenon. The excess force is usually designated as breakout force. The most significant component of the resistance force emanates from the ‘suction’ generated at the object invert where pore water pressure reduces to a value smaller than the hydrostatic pressure. During uplift the ‘suction’ will fade away due to dissipation of pore pressure, which may lead to an abrupt and significant reduction in uplift resistance. This characteristic is terminologically called breakaway where the interface at the invert cannot sustain tension any more. Studies on breakout phenomenon date back to 1960s for marine salvage operations. Nowadays, fully understanding the breakout process is more meaningful in offshore engineering, as it has a wide variety of applications, such as retrieval of offshore infrastructures due to decommissioning and securing anchorage foundations against lifting.

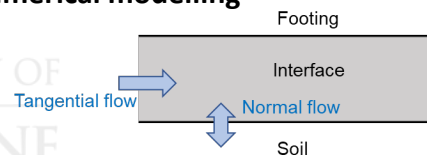
This thesis will explore the mechanism of the breakout process of uplifting shallow foundations on clay seabed. Centrifuge modelling was conducted to investigate the performance of shallow foundations under monotonic, sustained and cyclic uplift loading. A numerical interface model was developed to capture feature of uplifting process of shallow foundations in effective stress analysis.

## Centrifuge modelling



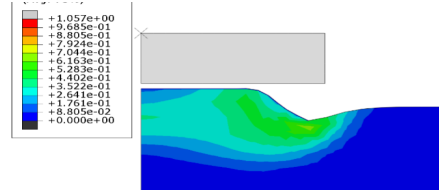
## FIGURE/DATA

### Numerical modelling



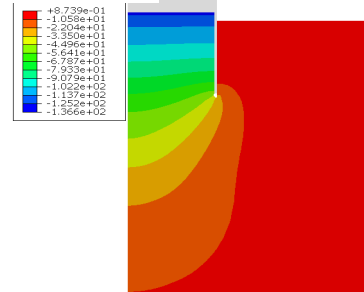
### Numerical interface

#### Plastic strain magnitude



### Simulation of uplifting surface footing

#### Excess pore pressure



### Simulation of uplifting skirted footing





# Identifying the Influence of Temperature on the Development of Initial Cement Debonding

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**Discipline:** Geotechnical

## ABSTRACT

The success of hydrogen storage in depleted hydrocarbon sites depends on the wellbore integrity provided by the existing completion technology. The development of microannuli can trigger gas migration through and around the cemented annulus. In this research work, an attempt was made to study the influence of different factors on the geometry, distribution and connectivity of microannuli. Composite samples were prepared with API class G wellbore cement and sandstones which were cured under different temperature conditions. The samples were then subjected to X-Ray CT scanning and analysis were performed in three dimensional space using AVIZO 2019.2.

## INTRODUCTION

Underground hydrogen storage in depleted hydrocarbon reservoirs can help Australia achieve the targets set in National Hydrogen Strategy through the utilization of renewable energy. The success of storage of hydrogen in depleted sites depends on the wellbore integrity provide by the existing completion technology. The microannuli formation due to cement debonding between the contact areas of wellbore cement with casing and formation rock can trigger gas migration through and around the cemented annulus. This can lead to significant loss of stored hydrogen and catastrophic accidents. The present work aims to study the geometry and distribution of microannuli in wellbores.

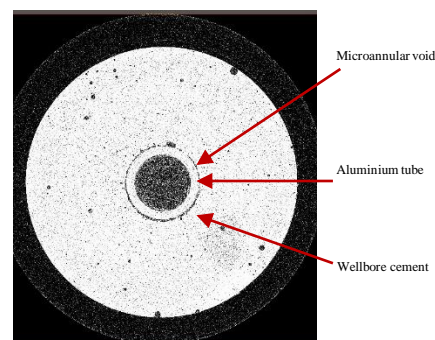
## DISCUSSION

The gas migration immediately after the cementing job is referred to as primary gas migration which occurs as a result of poor cement bonding between cement sheath and formation or casing. The present study focussed on evaluating the influence of temperature on cement-casing bonding. The nature of cement bond at the interfaces between cement-formation and cement-casing determines the ability of cement to resist flow and withstand load before failure. Cement bonding has been evaluated by different authors using different methods which include logging methods, shear bond strength tests, permeability and X-Ray CT scanning. The X-Ray based image analysis provides the benefit of actual determination of aperture, distribution and connectivity.

## METHODOLOGY

Composite samples were prepared with API class G wellbore cement and 10mm diameter Aluminium tubes to evaluate the microannular development between formation rock and wellbore cement sheath. The cement slurry was prepared in accordance with API 10A and poured into the moulds with aluminium tube centred to prepare 38mm diameter and 76 mm height composite samples. The composite samples were cured at different temperatures under atmospheric pressure for 24 hours. The prepared samples were then subjected to X-Ray CT scanning. The images were then reconstructed using AVIZO 2019.2 to perform three dimensional analysis.

## FIGURE/DATA





# Thermo-mechanical response of a thermo-activated soldier pile wall in the Melbourne Metro project

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## ABSTRACT

Energy pile foundations have been extensively studied during the last two decades as an alternative to supply the growing energy demand and to reduce the capital cost of shallow geothermal systems. The thermo-activation of traditional axially loaded foundations, and its derived conceptual framework has been extended to other energy geostructures. This study presents some results from a series of full-scale field tests of a soldier piled energy wall section comprising three piles. At the excavation completion, the piles were thermally operated and monitored to investigate the potential effects of continuous and cyclic thermal loads on the thermally induced strains within the piles. For the tested case, the results show negligible thermo-mechanical impact of these operational schemes. These may become important under other conditions.

## INTRODUCTION

The growing demand for highly efficient renewable energy technologies has positioned shallow geothermal energy as an attractive alternative. Traditional ground heat exchangers (GHEs) initial high capital cost, mainly associated with drilling, has extensively restricted their implementation. Conventional geostructures overcome this limitation and their use as GHEs is getting more attention. Nevertheless, existing guidelines are limited in practice, focusing on the short-term structural thermo-mechanical considerations in the energy pile foundations design.

## METHODOLOGY

A section of three piles of a soldier-piled retaining wall built in Melbourne's extension of the Metro line services is used as a case study. The piles are equipped with geothermal pipes and instrumented by strain meters and temperature sensors along their shaft. The system has been thermally activated within typical operation ranges and modes after excavation completion and lateral deformations stabilisation. A heating power of 6.1 kW from a Thermal Response Test unit was constantly and intermittently (12 h on/off) supplied to the system during a working week. Data was recorded during this operations.

## DISCUSSION

The pipes carrier fluid temperature (Fig. 1) rose from 16.2 to 24.8 °C during a continuous operation, and to 23.7 °C during the intermittent mode. The maximum temperature increment in the considered pile corresponds to 3.5 °C on the ground (G) side and 2.5 °C on the excavation (E) side under continuous operation. Fig. 2 presents the induced thermal strains on the excavation side compared with multiple construction stages before the activation. For this study, the measurements indicate that the induced thermal strains under continuous and intermittent operation during are within previous temporary construction stages, posing no thermo-mechanical issues.

## FIGURE/DATA

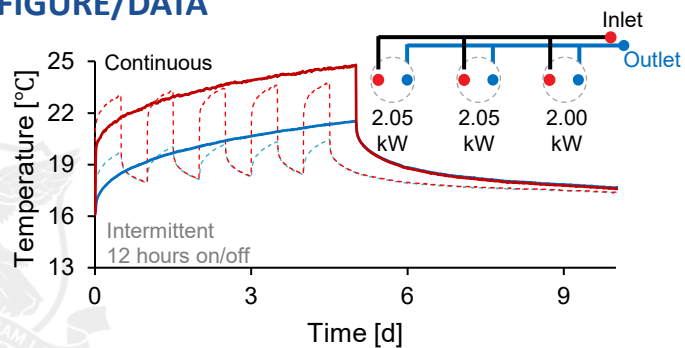


Fig 1. Pile inlet and outlet temperatures on continuous and intermittent modes.

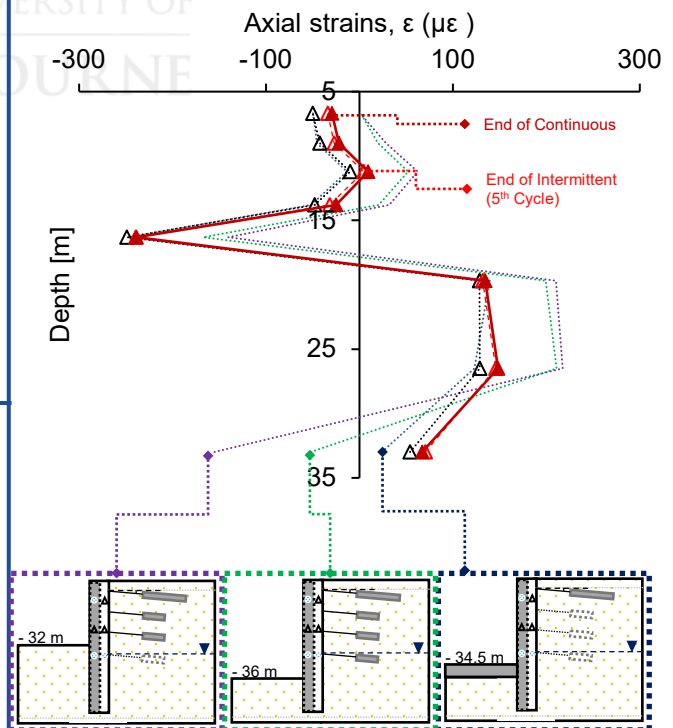


Fig 2. Thermally induced strains along the pile excavation side compared with previous construction temporary stages.





# Effects of horizontal connection pipes on the operation of borehole heat exchangers under different climatic conditions

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## ABSTRACT

Large bore fields with dozens or hundreds of borehole heat exchangers (BHEs) require long horizontal connection pipes to bridge the distances between the boreholes and the ground source heat pump use to heat and cool buildings. The heat transfer along these pipes is neglected in current design practice. As the heat transfer along the pipes is driven by the temperature difference between the heat carrier fluid and the surrounding ground, we investigate the effect of a 30 m connection pipe for 25 climate conditions around the world with a newly developed analytical model. The results show that the connection pipes have the most beneficial effect in tropical climates, leading to BHE load reduction of up to 35 % percent for the investigated scenario.

## INTRODUCTION

Shallow geothermal systems with several dozen or even hundreds of BHEs are increasingly being installed. In Sweden alone, the number of registered installations with 10,000 m or more total borehole length has almost quadrupled from 2015 to 2019. To engage a large ground volume, a minimum spacing of 6 m should be maintained between the BHEs, resulting in connection pipes of several dozen meters length between the BHEs and the heat pump (HP). The heat transfer along these connection pipes is not considered in current design guidelines and may impact thermal yields.

## METHODOLOGY

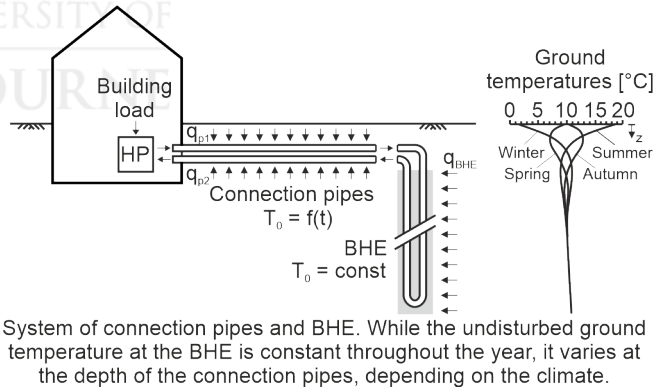
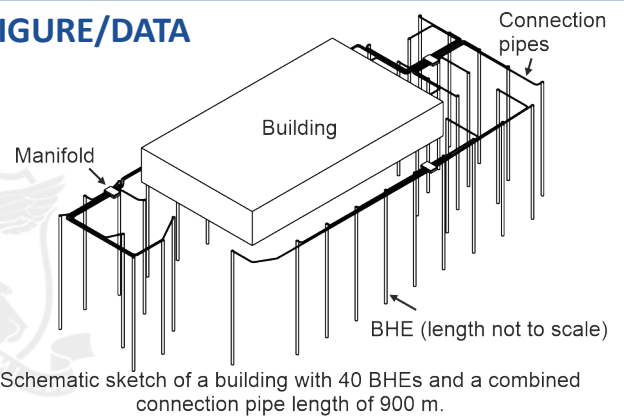
We developed a new analytical model based on thermal resistances and response functions to analyse the heat transfer along connection pipes and BHEs. For computational efficiency the simulation domain is split into multiple periods where the effect of already simulated periods on future periods is calculated using the Fast-Fourier-Transform.

The model is used to analyse the effect of a 30 m connection pipe buried at 1 m depth connected to a 100 m deep BHE in cities located in 25 different climates according to the Köppen climate classification.

## DISCUSSION

The consideration of a 30 m connection pipe can lead to a decreased BHE load of ~35 % for tropical climates. Due to the relatively constant seasonal air temperature, the underground temperature at the connection pipes is similar to the temperature at the BHE. The horizontal pipes can therefore be considered as an extension of the BHE. In arid and temperate climates, the decisive BHE loads are reduced as well, however with smaller absolute and relative numbers. Considering the connection pipes in future design practise can lead to reduced installation costs and therefore help to increase the share of renewable energies for heating and cooling of buildings.

## FIGURE/DATA



Climate	Total BHE capacity [MWh]	Yearly cooling [MWh]	Yearly heating [MWh]	Absolute change [MWh]	Relative change [%]	City
tropical	14.0	8.6	0.0	-5.1	+0.1	Kuala Lumpur
	14.1	8.6	0.0	-2.9	+0.1	Cairns
	14.1	8.6	0.0	-5.1	+0.1	Bangkok
	11.6	8.6	0.0	-4.2	+0.1	Mombasa
and	6.6	0.8	0.8	-1.5	+0.5	Cairo
	3.9	8.4	8.4	+0.31	-0.4	Isfahan
	2.8	5.7	5.7	-0.2	-0.5	Alicante
	0.5	6.7	6.7	+0.71	-0.2	Denver
temperate	1.6	6.3	6.3	-0.1	-0.8	Buenos Aires
	0.0	5.6	5.6	+0.01	-0.9	Auckland
	6.8	6.8	6.8	-1.3	-19.7	Reykjavik
	9.1	0.6	0.6	-2.3	+0.2	Hong Kong
continental	0.5	7.1	7.1	+0.81	-0.1	Chicago
	0.1	5.3	5.3	+0.81	+0.4	Moscow
	2.2	2.2	2.2	+0.7	+32.2	St. Moritz
	0.9	7.6	7.6	+1.0	-0.1	Bishkek

Impact of a 30 m connection pipe on a 100 m BHE. Total BHE capacity [MWh] (left) as yearly cooling (black) and heating loads (grey). Absolute [MWh] (middle) and relative [%] (right, capped at 100 %) changes in BHE load due to consideration of connection pipes.





THE UNIVERSITY OF  
MELBOURNE

# OCEAN ENGINEERING



# Projected wave climate of Bass Strait and south-east Australia by the end of the 21<sup>st</sup> century



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**Discipline:** Ocean Engineering

## ABSTRACT

A high-resolution third-generation wave model based on unstructured grids was used to study the projected future wave climate of Bass Strait and south-east Australia under two different greenhouse gas emission scenarios (SSP1-2.6 and SSP5-8.5). The projected mean significant wave height ( $H_s$ ) for SSP5-8.5 by the end of the 21st century (2071-2100) shows a robust increase for the majority of the domain, but a decrease in nearshore regions, mainly due to projected decreases in local wind speed. The increase in  $H_s$  for SSP1-2.6 is relatively small. Extreme value analysis shows a stronger increase in extreme wave climate for SSP5-8.5 than for SSP1-2.6. Extreme  $H_s$  for SSP1-2.6 shows a projected decrease in western regions of the domain and an increase in the east. Extreme  $H_s$  for SSP5-8.5 shows a decrease in the nearshore areas of Victoria.

## Research domain

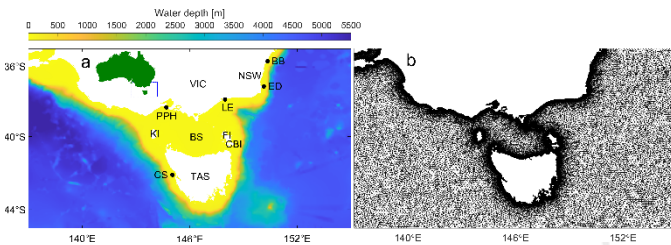


Fig.1 (a) Water depth and (b) model grids.

## Model validation

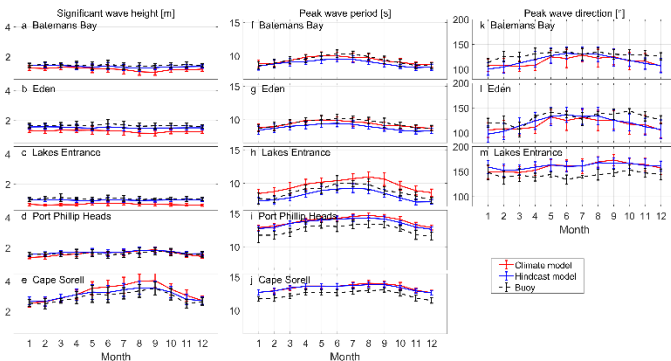


Fig.2 Comparisons between the model results and buoys.

## Results

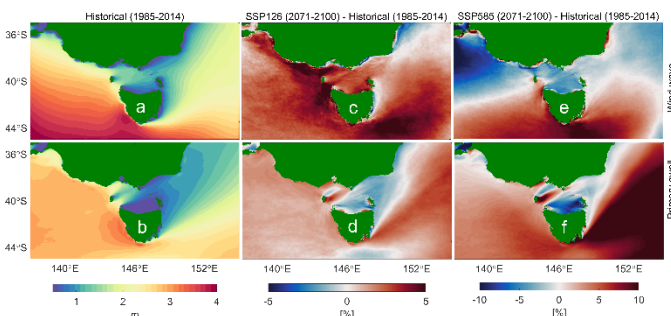


Fig.3 Partitioned wind sea and swell over the historical period and their projected changes by the end of 21<sup>st</sup> century.

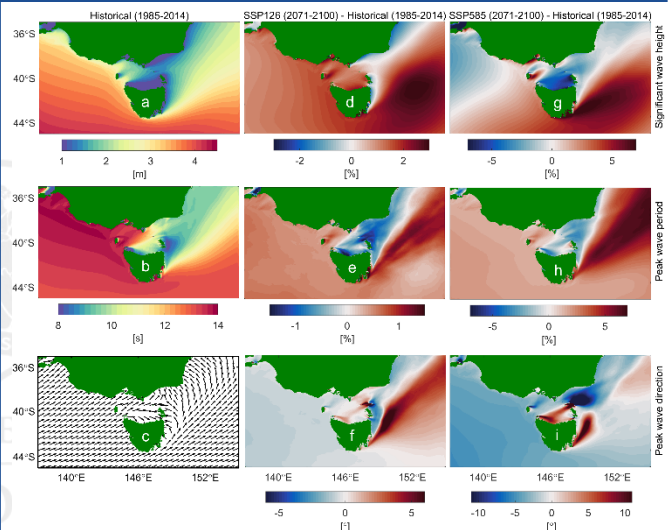


Fig.4 Mean values of  $H_s$ ,  $T_p$  and  $D_p$  over the historical period and their projected changes by the end of 21<sup>st</sup> century.

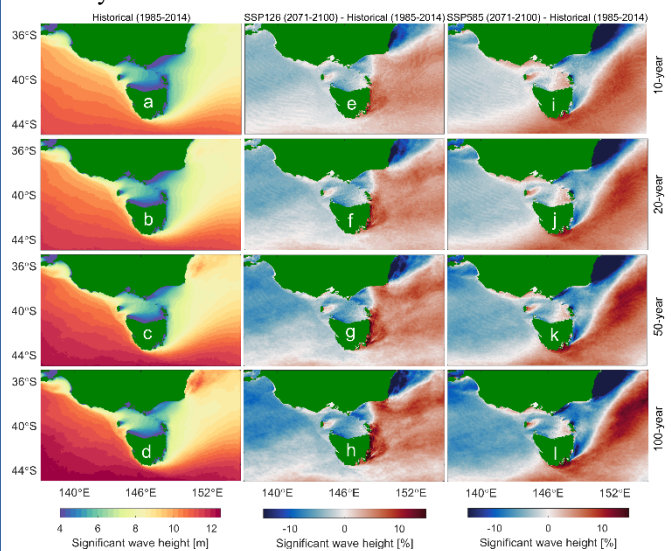


Fig.5 Extreme  $H_s$  for different return periods over the historical period and their projected changes by the end of 21<sup>st</sup> century.







# Observation based source terms: Validations and spatial analysis of high-resolution wave hindcast in Arabian sea

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**Discipline:** Ocean Engineering

## ABSTRACT

Arabian sea is unique with respect to its climatology, having distinctive low - moderate and high wind seasons as well as multiple wind/ swell systems. Wave forecast models employ different source terms parameterizations to predict waves, that are generally tuned to give accurate wave forecast in different regions. Validations of WAVEWATCH-III wave forecast model are carried out with globally calibrated satellite altimeter's dataset. The statistical analysis of model's performance indicates relatively weaker performance during low wind conditions compared to high wind regimes. Model overestimated the significant wave height during the Pre-Monsoon and Post-Monsoon seasons compared to the high intensity Monsoon season despite having a negative bias in wind forcing.

## INTRODUCTION

Arabian Sea has a very distinctive climatology that is characterized by different wind and swell systems. The climatology of Arabian Sea is dictated by the dominated North Easterly (NE) and South Westerly (SW) Monsoon winds that influence the wind-wave generation. The seasonal climatic variations in the region form three different distinctive seasons in Arabian sea known as Pre-Monsoon (Feb – May), Monsoon (Jun-Sep) and Post-Monsoon (Oct – Jan). The Makran mountain ranges near the coast of Pakistan, in Baluchistan province, further modify the northerly wind system in Arabian sea to generate Makran winds.

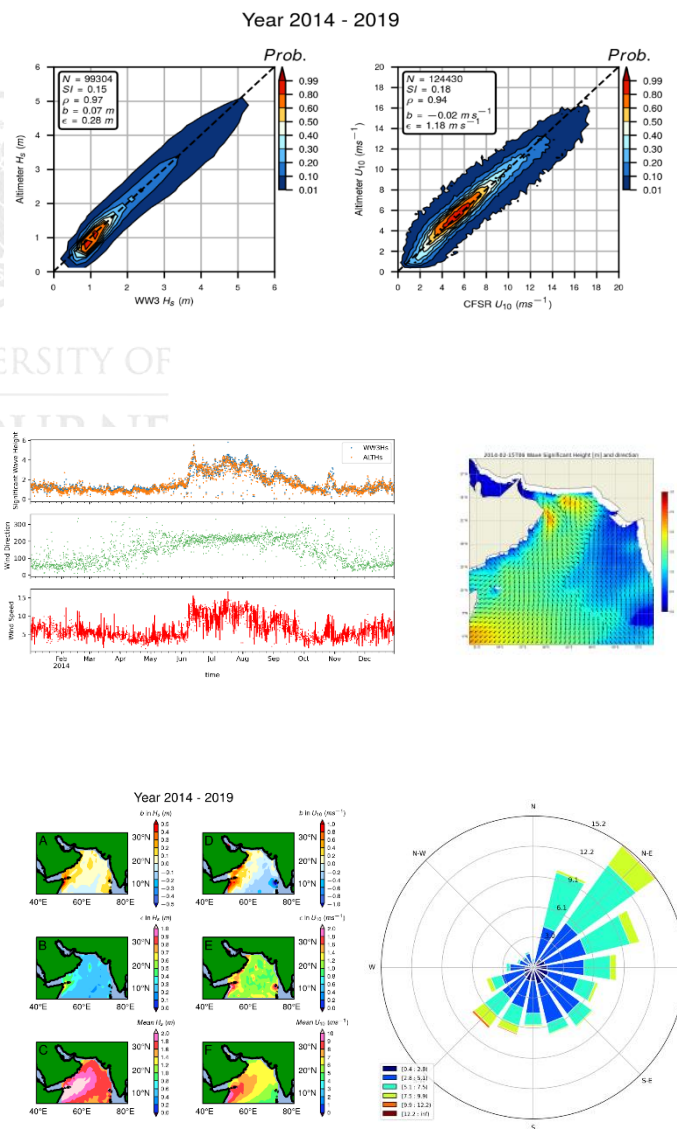
## METHODOLOGY

This study aims to test the observation-based physics package ST-6 in Arabian Sea with emphasis to generate local wave forecast with highest accuracy possible. Initially, WAVEWATCH-III model's performance is analyzed by using both CFSR and ERA-5 wind forcings. Further, a 5 year hindcast is obtained to analyze the model's performance during different local seasons. Also, the interaction of various dominant local swell systems in Arabian sea during Non-Monsoon seasons and its impact on model's performance is investigated.

## DISCUSSION

WAVEWATCH-III model performs better with current configurations when forced with ERA-5 winds as compared to CFSR winds. Model performed relatively poor under low wind conditions and overestimated the significant wave heights during Non-Monsoon seasons. Different wind and swell systems are dominant in the region that greatly influence the performance of wave forecast models. The local wind-wave climate is influenced by NE, SW swell systems as well as Southern Ocean, Makran and Shawal swells.

## FIGURE/DATA





# Automated identification of sea ice floes from digital images

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**Discipline:** Ocean Engineering

## ABSTRACT

The floe size distribution (FSD) is an important parameter for sea-ice statistics, challenging to estimate due to difficulties in ice floe identification, particularly the separation of ice floes that typically touch each other in the ice-covered environment. Despite its importance, a technique to efficiently extract this information still lacks and the majority of sea ice characteristics reports existing in the literature are based on visual observation from ships or, on a larger scale, inferred from satellite imagery. Here, an automated method to detect sea ice floes is discussed and applied to close-range optical ice imagery acquired aboard the South African icebreaker S.A. Agulhas II during winter Antarctic expeditions.

## INTRODUCTION

Sea ice covers about 7% of the Earth's surface and plays a pivotal role in the global climate system. Variations in ice condition and extent affect environment, wildlife, human activities and are deeply connected to the climate change. Estimating the FSD contributes to describing these variations and their effects on a global scale, and is a key question facing climate modellers. In this study, image processing algorithms to automatically identify ice floes and extract the FSD are applied to images recorded by a monochromatic camera installed on the icebreaker S.A. Agulhas II.

## METHODOLOGY

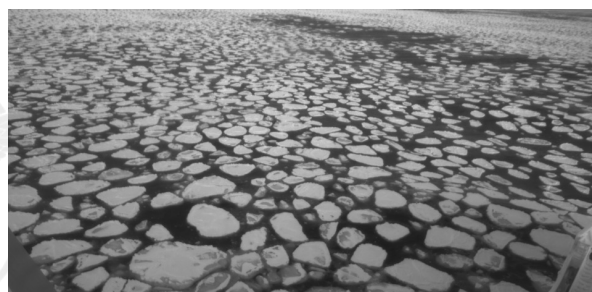
- Images acquisition
- Perspective correction
  - Camera calibration to estimate the intrinsic parameters
  - Field measurements of the extrinsic camera parameters
- Ice floes detection
  - Pre-filtering to adjust the contrast of the image
  - Gradient vector flow (GVF) snake algorithm
  - Post-cleaning to remove artefacts
- Labelling and floe size extraction

## DISCUSSION

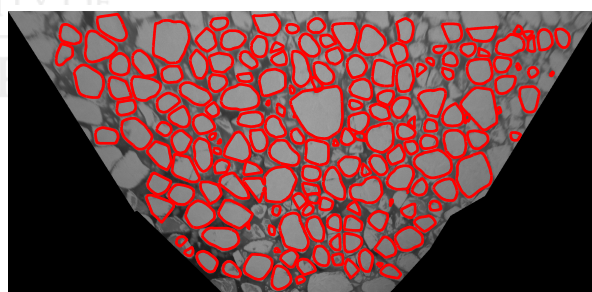
The automated image processing method proposed shows a good degree of reliability as demonstrated by the comparison with the FSD of a random sample of images in which floes have been manually segmented. However, some results require to be discarded to improve the quality of the data, especially those obtained from images recorded at night or in poor visibility conditions.

In addition, the algorithm is not yet able to discriminate between different types of ice and the computational time is quite high, about 25 seconds per ice floe.

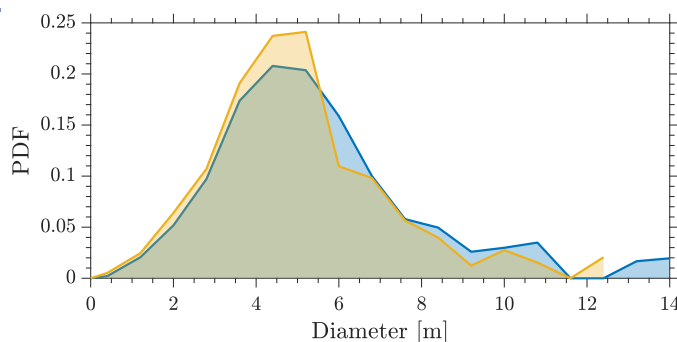
## FIGURE/DATA



Sample image recorded by ship-mounted camera.



Perimeter (red) of all floes identified by the GVF snake algorithm after cleaning artefacts.



Comparison of automated FSD (yellow) and manually-selected FSD (blue) for a random sample of images





# SWELL DISSIPATION IN THE WAVEWATCH III MODEL WITH THE ST6 SOURCE TERM PACKAGE

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**Discipline:** Ocean Engineering

## ABSTRACT

More than 75% of the ocean is dominated by storm generated oceanic swell. The pioneering field studies of Snodgrass et al (1966) showed that such swell waves can propagate across oceanic basins with little decay. Although swells play an important role in the wave climate, the current understanding on swell propagation and related physical processes is incomplete which has led to poor swell predictions. The main aim of this study is to investigate the performance of the wave model WAVEWATCH III in simulating swell propagation and dissipation using Sentinel-1 satellite data.

## INTRODUCTION

High energy swell conditions can cause serious coastal hazards such as nearshore flooding, inundation, beach stability and harmful effects for coastal and offshore operations. The need to measure decay over large scale oceanic basins, limitations in measuring instruments and an incomplete theoretical understanding of the active processes responsible for swell decay have hampered a comprehensive understanding. As a result, predictions of swell propagation and decay in present day spectral wave models represents a significant error source (Tolman and Chalikov, 1996). This study focuses on swells generated at Campbell Island in the Southern Ocean and propagating across the Pacific Ocean for four years (2017-2020). The performance of the swell dissipation term in the WAVEWATCH III (WW3) model is investigated using Sentinel-1 satellite data.

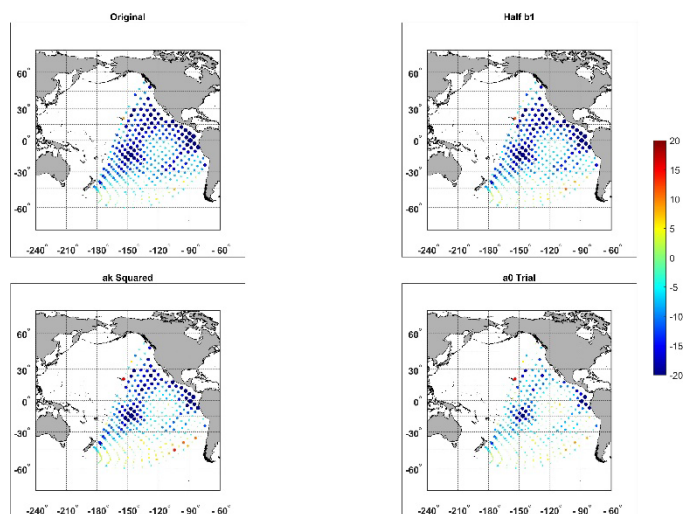
## DISCUSSION

- The total significant wave height extracted from the directional spectra of WW3 and Sentinel-1 showed relatively good agreement.
- The normalized bias across the Pacific Ocean is negative and reduces along the distance which suggest that the model dissipates more than energy than observation data.
- Higher negative biases were found in the area where Pacific islands are found which proves that the model is unable to solve the directional spectra near land areas.
- An improvement in the WAVEWATCH III model was in the test where the negative wind input was reduced.

## METHODOLOGY

- A global implementation of the WW3 wave model was run with ERA5 defined wind and sea ice.
- Swell events generated at Campbell Island were identified by selecting peaks above or equal to 4m from the modelled significant wave height and filtering them with waves travelling towards angles between  $0^{\circ}$  to  $180^{\circ}$ .
- Swell events were tracked along 19 swell paths equally spaced at  $5^{\circ}$  angles defined covering the Pacific Ocean.
- A WW3 model with ST6 parametrization was run with wind, sea ice and current forcing and model performance was analysed by considering the normalized bias between the model and observation wave heights along each path.
- Three different test runs were simulated to optimize the model.
  - i. Reduce the tunable coefficient in the swell dissipation term
  - ii. Squaring the wave steepness term in the swell dissipation term
  - iii. Change in the negative wind term

## FIGURE/DATA



# Surface Heat and Moisture Exchange in the Antarctic Marginal Ice Zone: Field Observations and Model Comparison



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**Discipline:** Ocean Engineering

## ABSTRACT

Infrared (IR) thermal camera images acquired during winter and spring from an ice-going vessel reveal thermal inhomogeneity of the Antarctic marginal ice zone at the centimeters to meters scale, with contrasting temperatures in the open water cracks and solid sea ice floes, up to 5°C in winter. Measurements show that ERA5 reanalysis temperature, which compares well in the open ocean and in compact ice conditions towards the interior of the marginal ice zone, is significantly lower in the marginal ice zone, by up to 5°C and 2°C in winter and spring, respectively. We use the measured sea-ice surface temperature (S-IST) to estimate the heat fluxes in the Southern Ocean and demonstrate that the ocean heat loss is significantly larger than the one predicted using the reanalysis product.

## INTRODUCTION

The Antarctic sea ice is one of the largest and most dynamic ecosystems on Earth and plays a crucial role in the Earth's climate system. However, heat fluxes over sea ice are poorly constrained, particularly in the marginal ice zone (MIZ) due to the inhomogeneity of the sea ice surface. We measured climatic variables aboard the icebreaker during two voyages to the Antarctic MIZ in winter and spring. In-situ measurements are used to assess model uncertainties via comparison with ERA5 reanalysis. We demonstrate that biases in the S-IST affect the estimation of the surface energy fluxes.

## METHODOLOGY

A thermal infrared imaging camera was used to measure the S-IST along the ship tracks (fig.1). On board we measured the atmospheric and oceanic variables involved in the estimation of the surface energy fluxes, such as wind speed, air temperature, relative humidity, solar radiation ( $Q_s$ ), and cloud coverage. Through the bulk equations of the long-wave radiation ( $Q_b$ ) and turbulent heat fluxes ( $Q_e$  and  $Q_h$ ), we estimated the surface energy fluxes (fig.2), and then we compared the results with ERA5 reanalysis estimations (fig.3).

## DISCUSSION

The S-IST comparison between observations versus ERA5, highlights that the biases are significantly less in open ocean, instead, over the MIZ, the model is less accurate. Moreover, during the winter season, model underestimates the S-IST up to 5°C in frazil/pancakes conditions due to an increase in the heterogeneity of surface properties. We demonstrated how the biases in the S-IST significantly influence the estimation of the heat gain or loss from the ocean in terms of thermal radiation ( $Q_b$ ) and evaporative flux ( $Q_e$ ) over the MIZ.

## FIGURE/DATA

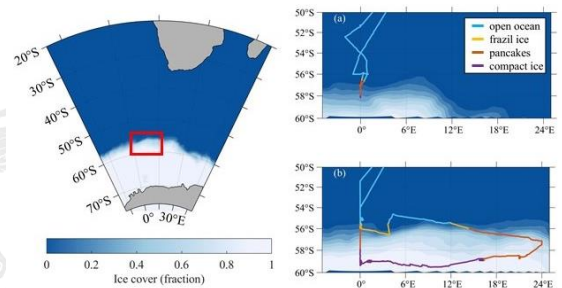


Fig.1 Ship routes in the Antarctic MIZ with sea ice fraction averaged over the field campaigns period.

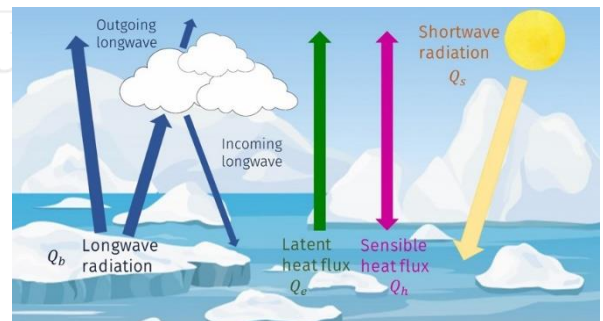


Fig.2 Surface heat fluxes scheme.

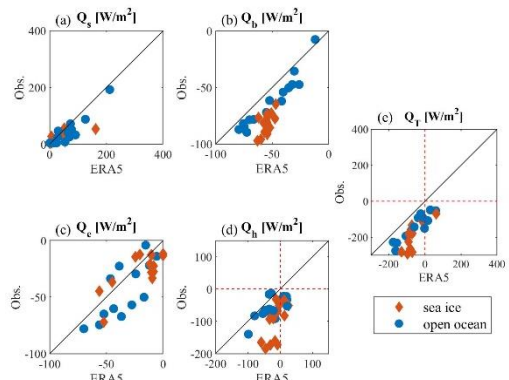


Fig.3 Scatterplots of ERA5 versus field observations for surface energy fluxes.



# HURRICANE WAVES SIMULATION USING AN UPDATED WIND VORTEX MODEL



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**Discipline:** Ocean Engineering

## ABSTRACT

This paper simulates historical North Atlantic hurricanes using an updated parametric wind vortex model and evaluates its application to perform wave model simulations to generate wave fields in tropical cyclone conditions. The reconstructions of these past storms and the comparison of the modeled waves with buoy measurements indicated good agreement. In conclusion, this study demonstrate that for more practical and quick response use, this updated parametric wind model is a good option to provide meteorological forcing in wave models for both hindcasts and forecasts purposes in extreme wind events.

## INTRODUCTION

Waves generated by tropical cyclones (TCs) can cause damage to offshore structures and coastal settlements and play an important role in the design criteria for engineering projects, risk assessments and insurance purposes. Among several factors, an accurate wave field prediction depends on a well-defined wind field, what it is more complex in the case of TCs, as wind speeds and directions change rapidly in space and time.

There are several parametric surface wind field models for TCs, and many studies evaluating them. The Holland et al.(2010) parametric wind model, despite some limitations, has been widely used to determine the surface (10m) wind speed. In this study this model was improved and its ability to generate reasonable wave fields was validated by applying it to hindcast conditions for historical North Atlantic hurricanes.

## DISCUSSION

In the analysis, the integral and spectral wave parameters were validated against data from NOAA's National Data Buoy Center (NDBC). The maximum calculated significant wave height ( $H_s$ ) induced by the hurricane's synthetic wind field are shown on Figure 1 against buoy data for the hindcast of hurricane Earl (2010). The results showed reasonable agreement with both negative and positive biases. Note that the parameters used to define the wind fields were taken from IBTrACS dataset and no attempt was made to optimize these.

For all eight historical hurricanes simulated, the wave results from the WW3 model, forced by the parametric TC wind field, compared reasonably well with the buoy data for integral wave properties and directional spectra. These results provide confidence in the performance of the updated wind parametric model for further use in wave predictions for TC events.

## METHODOLOGY

The TC wind vortex model of Holland et al. (2010) was extended to include asymmetry and variable wind inflow angle using the observational results of Tamizi et al. (2020). Parametric relations were developed for inflow angle resulting in the parameterized inflow angle equation:  $\theta = a * \cos(\alpha + \varphi + \theta_{fm}) + b$ ; where,  $\theta$  is the inflow angle,  $a$  is a scaling constant,  $\alpha$  is the azimuthal angle,  $\varphi$  is the phase shift of the maximum inflow,  $\theta_{fm}$  is the direction of propagation of the tropical cyclone,  $b$  is the offset dependent on the radius of maximum winds ( $R_{max}$ ). This model generated a parameterized vortex capable of reproduce TC wind fields using wind parameters from the IBTrACS dataset (Knapp et al., 2010).

These TC wind fields were used to force the WAVEWATCH III (WW3) spectral wave model (WW3DG, 2019) using two different source term packages for eight historical North Atlantic hurricanes and the wave parameters were validated against NDBC buoys.

## FIGURE/DATA

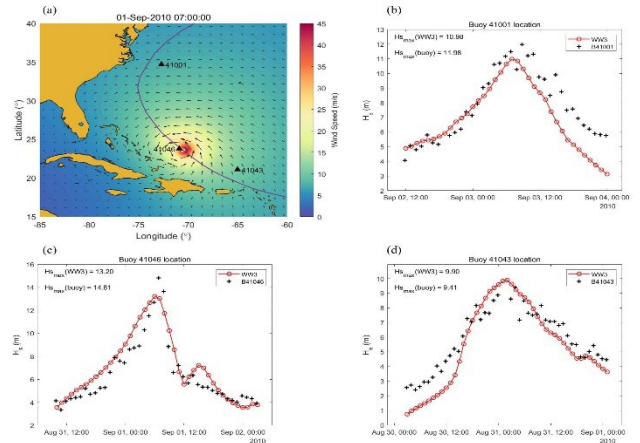


Figure 1 - (a): Wind field for the Hurricane Earl on 01 of September of 2010 (velocity coloured on m/s and vector direction not scaled). (b), (c) and (d):  $H_s$  comparison between WW3 and Buoys 41001, 41046 and 41043, respectively.





THE UNIVERSITY OF  
MELBOURNE

# STRUCTURAL ENGINEERING





# Façade Materials as Part of Circular economy in Australia

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## ABSTRACT

Circular Economy has become a largely discussed topic in the recent years. The aim of this study is to identify how façade materials, in particular aluminium composite panels with polyethylene core (ACP-PE cladding), can be part of circular economy in Australia. In order to achieve the aim of this study, 40 interviews were conducted with industry professionals from junior engineers to top managers in organisations representing engineering consulting, design, building contractors, building services, and the local government. Additionally, a systematic literature review was conducted to identify the opportunities for the use of end-of-life cladding waste. The outcomes revealed that although there are multiple potential solutions for using end-of-life cladding waste for new products, there is no universal measure of circularity and, therefore, it is difficult to draw comparison on how well organisations are performing.

## INTRODUCTION

Circular Economy has received a lot of attention in the last years. However, it is still unclear how different processes and products could be part of this concept. The goal of this study is to identify how ACP-PE cladding from Australian buildings can contribute to circular economy. In particular, this study is focusing on the challenges related to application of circular economy in the infrastructure sector and potential of materials derived from end-of-life cladding to be brought back to the loop to bring Australia closer to achieving circular economy.

## METHODOLOGY

40 semi-structured interviews with the industry professionals within the infrastructure engineering sector with a particular focus on facades were conducted. The respondents represented design, construction, demolition, engineering consulting companies, as well as the local government (councils) recruited via email and LinkedIn. The analysis of the interview data was implemented using the qualitative data analysis computer software NVivo. The potential opportunities for the ACP-PE cladding were identified by a systematic literature review using the PRISMA statement.

## DISCUSSION

The infrastructure sector overall is a large contributor to waste. Large volumes of end-of life materials, are sent to landfills. Currently, there is no solution on how façade waste can be used to produce new value-added materials. However, the possible opportunities include industrial packaging, low-pressure pipes and footwear. Furthermore, there is no uniform measure of circularity, making difficult to identify how well certain products and processes are performing as part of circular economy. Therefore, this research will further explore how circularity can be measured and applied in the infrastructure sector in Australia, with a particular interest in cladding materials.

## FIGURE/DATA

Method	RQ1: What are factors and antecedents of a good and sustainable circular model?	RQ2: What is a good measure of circularity in CE concept?	RQ3: How do we encourage companies to adopt CE models?
Systematic literature review	✓	✓	
Interview		✓	✓
Model development		✓	
Case study (model validation)		✓	✓

Figure 1. Research methods



Figure 2. Interview findings



Figure 3. Literature review findings





# Analytical modelling of contact forcing function of hailstone impact

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**Discipline:** Engineering Management

## ABSTRACT

The contact forcing function (of time) generated by the impact of hailstone is crucial to reliable predictions of damage to cladding and glazing panels. An analytical model has been developed and validated for predicting this forcing function which is dependent on the size of the hailstone, its temperature, and velocity of impact. The development of this model was justified, as existing analytical models would only give accurate prediction of the peak contact force but not the time history. The model has been calibrated and validated against experimental results taken from 19 impact tests which employed a modified Hopkinson bar for measurement of the contact force. Such an experimentally validated predictive model provides an easy approach to be used in day-to-day engineering practices.

## INTRODUCTION

Hailstorm events can cause widespread destruction to building facades and roofing panels. Past events have resulted in billions of dollars of damage. Impact of hailstones can cause permanent indentation into metal cladding which may result in perforation leading to the ingress of water, or at least jeopardise the aesthetics of the built facility. Accurate estimation of the potential damage to cladding panels requires a good understanding of the contact forcing function which happens between the hailstone and the target surface. A versatile and easy to apply model is therefore preferred and developed.

## METHODOLOGY

The development of this analytical model incorporated evolution of the effective mass and contact stiffness of ice during the course of the impact. The model is based on a two-degree-of-freedom (2DOF) spring connected lumped mass system. Four parameters characterising the model were calibrated against eight sets of results from impact experimentation involving use of the gas gun. The calibrated model was then validated by comparison with another 11 sets of results which had not been involved in the calibration process.

## DISCUSSION

The proposed deterministic analytical model provides accurate prediction of the contact forcing function of hail, and requires only knowledge of the diameter, temperature, and velocity of impact of the ice impactor as input parameters. The model can be used for predicting indentation into aluminium claddings, and stresses of different forms on a target made of a brittle material such as glass. One limitation of the model is the assumption of a rigid target. The contact force behaviour can be notably influenced by the mass and stiffness of the target. Considerations of the flexibility of the targeted structure should therefore be incorporated into future studies.

## FIGURE/DATA

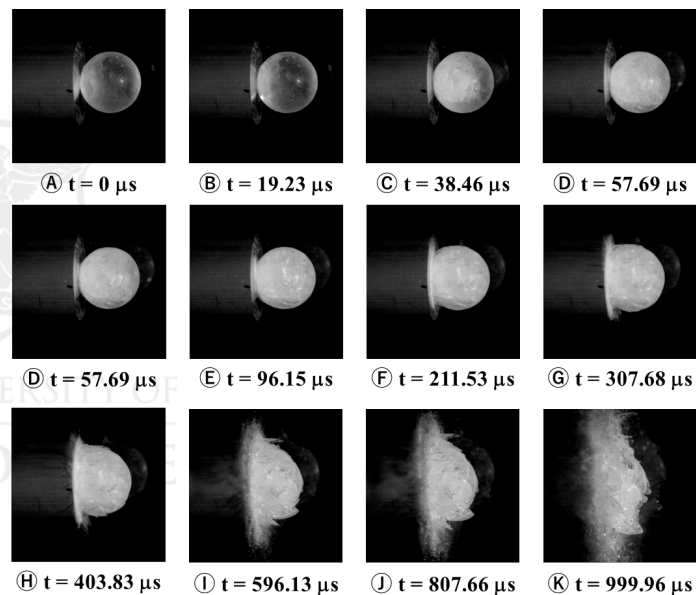


Fig. 1. High speed camera captured images showing fragmentation of the ice specimen during impact

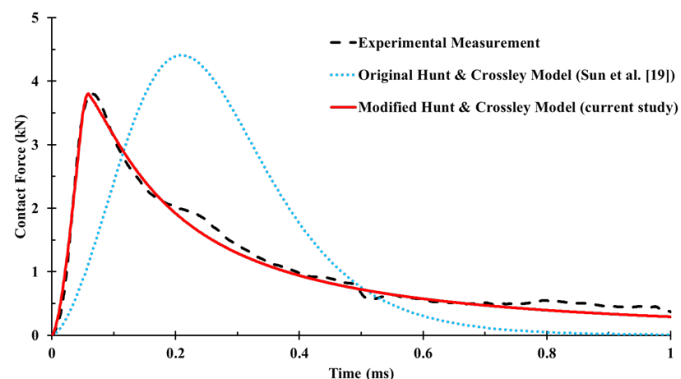


Fig. 2. Comparison of contact force time histories measured from experiments and simulated by the proposed analytical model







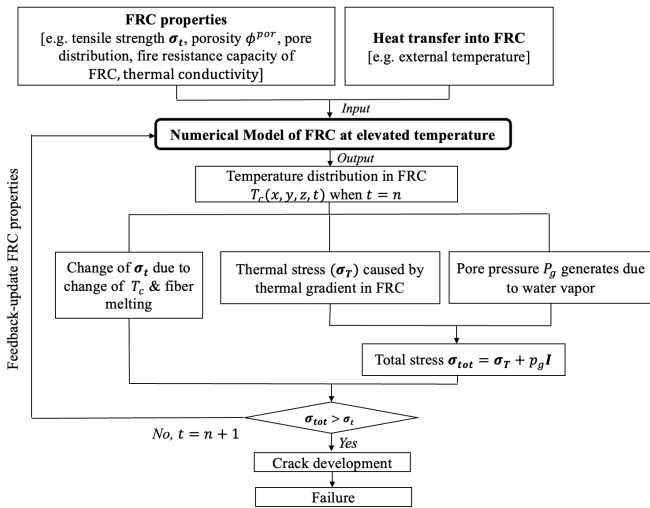
# Numerical Investigation on heat & moisture transfer and pore pressure within FRC and EFFRC at elevated temperature

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## ABSTRACT

A system of coupled transient differential equations governing heat transfer, water vapor transfer, and pore pressure built up in concrete, subjected to intensive heating, was derived. Hill Function was used for studying the dose-response relationship between water evaporation rate and pore pressure. Water vapor and liquid water were considered separately in the mass transfer formulation, while the phase of air was neglected in the current study. The primary unknown independents were temperature, the volume fraction of water vapor, and pore pressure. The effect and property change of fiber at elevated temperature were considered as variables in the relevant equations. The present numerical results showed good agreement with the previous experimental results.

## INTRODUCTION



## DISCUSSION

The curves of present results and the ones of experimental data matched well. It should be noticed that when the heating time came to 175 min, temperature and pressure gaps between numerical and experimental data occurred. Since the concrete specimen chosen exhibited a relative low permeability, moisture clog might occur, leading to higher pore pressure near the surface and cracking. As a result, the internal part of concrete was directly exposed to heat source, causing that temperature rose rapidly. The pore pressure distribution of the numerical model along the depth of the specimen was compared to the experimental results in Ye Li. It is evident that the predicted pore pressure curves from the FE model share the same trends, as well as the similar occurring time and values of peak points with the testing results, which indicates that the present numerical results are in accordance with the experimental ones in general.

## METHODOLOGY

### 1. Conservation of mass & Darcy's Law & ideal gas equation

Water:

$$\frac{\partial[\rho^l(\phi^{por} - \phi^g)]}{\partial t} + \nabla \cdot [\rho^l(\phi^{por} - \phi^g) \frac{\kappa}{\mu^l} \nabla p_g] = \dot{S}^{de} - \dot{S}^{evap}$$

Water vapor:

$$\frac{\partial[p_g/(R^g T) \cdot \phi^g]}{\partial t} + \nabla \cdot [p_g/(R^g T) \cdot \phi^g \frac{\kappa}{\mu^g} \nabla p_g] = \dot{S}^{evap}$$

### 2. Conservation of energy (Fourier's Law)

$$(\rho^c C) \frac{\partial T}{\partial t} + \nabla \cdot (-k \nabla T) = -\lambda_e \dot{S}^{evap} - \lambda_d \dot{S}^{de}$$

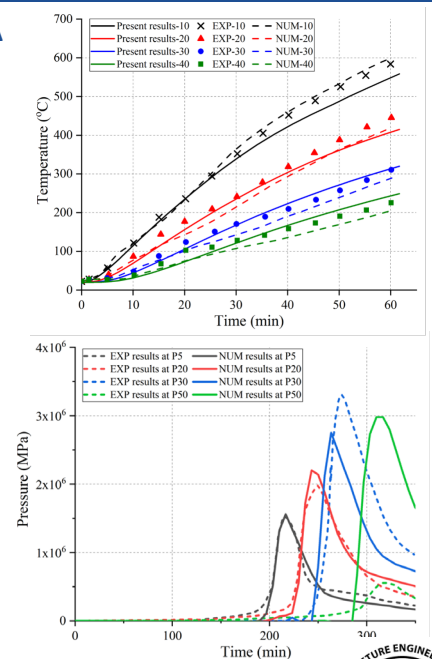
### 3. Conservation of linear momentum

$$\left[ \frac{E\nu}{(1+\nu)(1-2\nu)} \nabla(\nabla \cdot \mathbf{u}) + \frac{E}{(1+\nu)} \nabla^2 \mathbf{u} \right] - p_g \mathbf{l} = 0$$

### 4. Hill Function

$$\frac{P_t}{P_0} = \frac{P_{max} \left( \frac{T_t}{T_0} \right)^w}{Kw + \left( \frac{T_t}{T_0} \right)^w}$$

## FIGURE/DATA





# The effects of mechanical instability on PDGF mediated inflammatory response at early stage of fracture healing under diabetic condition

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## ABSTRACT

Excessive interfragmentary movement will continuously damage the tissue and newly formed capillaries at the fracture site, ultimately persistent and enhanced inflammatory response happens. For diabetic condition, the impact of mechanical instability of fracture site on inflammatory response could be further complicated and the relevant research in this field is relatively limited. This study presents a numerical model for studying the role of mechanical stability of fracture site in inflammatory response during early stage of healing. The result shows that the mechanical instability together with diabetic condition can significantly affect the natural resolution of inflammation during early stage of healing by turning acute inflammation into chronic inflammation which is characterized by a continuously upregulated TNF- $\alpha$  pathway.

## INTRODUCTION

This study aims to develop a computational model simulating the inflammation process of mechanically stable and unstable fracture healing. In addition, the effect of the change in mechanical microenvironment on the change of the inflammatory response is also investigated. The outcomes of this research could provide researchers with a better understanding of the bone healing process under the influence of mechanical factors and could help clinical practitioners design better treatment methods for their patients as well.

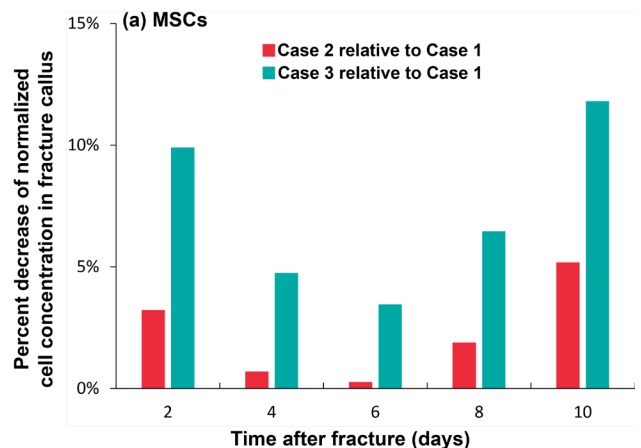
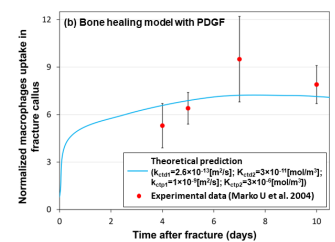
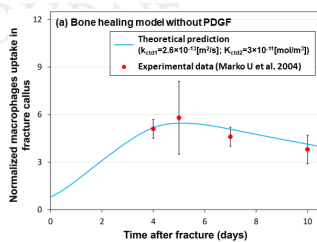
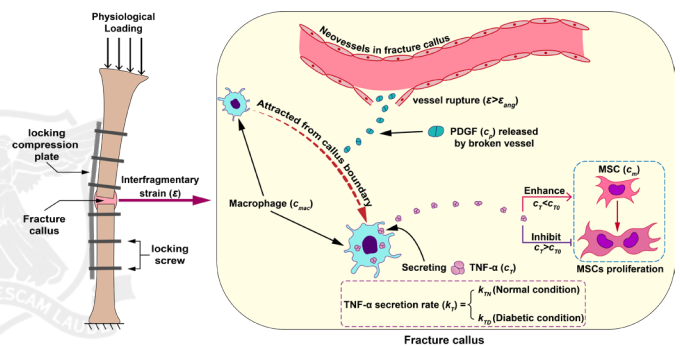
## METHODOLOGY

Building on previous experimental studies, this study presents a numerical model for studying the role of mechanical stability of fracture site in inflammatory response during early stage of healing. It is assumed that there is an increased release of PDGF due to the rupture of blood vessels resulting from mechanical instability, which leads to increased production of inflammatory cytokines. The bone healing process under three different conditions were investigated.

## DISCUSSION

The model predictions demonstrate the critical role of mechanical instability in regulating the initial inflammatory response and inflammation resolution by stimulating macrophage aggregation and pro-inflammatory cytokine (i.e., TNF- $\alpha$ ) releasing. The impairing of MSCs proliferation consequently inhibited the differentiation of osteoblasts and chondrocytes (Figure 6 b-c), which could finally progress to unsuccessful fracture healing.

## FIGURE/DATA





# Structural Performance of Hybrid Timber Composite Floor Slab Exposed to Fire

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## ABSTRACT

Increasing demand for building construction and the subsequent carbon footprint produced has led to an increase in interest in sustainable construction materials. This includes hybrid timber composite structures formed by composites with concrete or steel. Due to the usage of timber, fire is a major concern for the design and regulation of the structure, leading to a need to understand and predict the fire performance of the structure. This research aims to simplify the process required for engineers to assess and design for the structural performance of hybrid timber composite floor systems by proposing a novel fire performance assessment framework.

## INTRODUCTION

Hybrid timber composite floor systems are an environmentally sustainable alternative construction solution to conventional steel and concrete structures. The system benefits from the advantages of mass timber structures, such as high strength-to-weight ratio and low carbon footprint. The steel and concrete used in the timber composites allows for more efficient usage of materials, improving the strength and stiffness of the system relative to timber alone. The composite structure resolves some weaknesses of conventional timber structures, such as long-span applications, acoustic and vibration, and brittleness. Due to the presence of combustible timber material in the composite structure, there are concerns regarding the fire safety and structural integrity of hybrid timber composite systems.

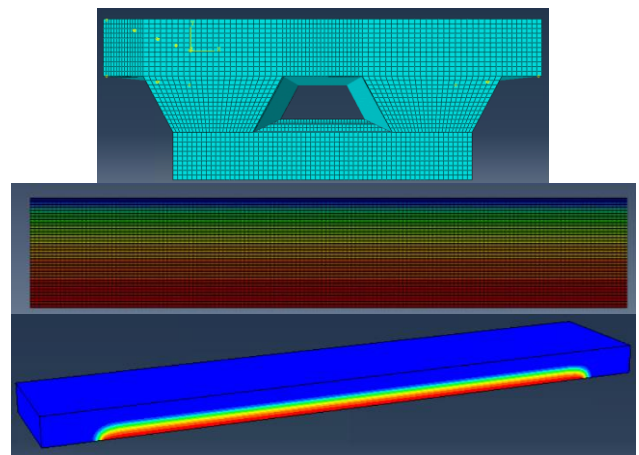
## DISCUSSION

- ABAQUS finite element package used as the primary tool for simulations
- Heat transfer analysis to be performed on the models based on temperature data from full-scale fire test
- Structural analysis to be performed on the models based on data from bending test performed at ambient temperature
- Sequential thermomechanical analysis to be performed on the models based on data from full-scale fire testing

## METHODOLOGY

- Review of the performance of timber and timber-composite structures exposed to fire
- Review of the simulation methods and models for timber, steel and concrete composite structures
- Perform preliminary finite element analysis based on the data and models found in literature
- Analyse experimental data from full-scale fire testing for a case study hybrid timber floor system
- Develop finite element model for hybrid timber floor system
- Validate finite element model with experimental data
- Perform parametric study of different design factors using the validated simulation model
- Develop a performance assessment framework for hybrid timber floor systems based on the parametric study

## FIGURE/DATA



- Examples from ABAQUS simulations

# Engineering Modular Building Towers for Improving Earthquake Safety



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## ABSTRACT

A modular building is formed by modules that are prefabricated in a factory and then assembled on site. It has the merit of minimising site work, thereby saving construction time. The lateral stability of a pure modular building relies fully on bolted connections. Failure of bolted connections in earthquake may trigger overturning of the tower. An effective method of improving the seismic performance is to apply rocking prestress using vertical superelastic tendons. Shaker table testing demonstrating the effectiveness of the rocking mechanism is presented. The effectiveness of a superelastic tendon in enhancing the seismic performance of the building is also demonstrated.

## INTRODUCTION

Instead of simply strengthening the connections, a self-supported modular building should respond to strong ground shaking in a robust, and reliable, manner with low risk of overturning. The authors advocate the concept of using rocking mechanism for enhancing the potential seismic performance. Incorporating superelastic tendons into the rocking system is beneficial for achieving a balance between mitigating internal force demand within the building and controlling the overturning risk.



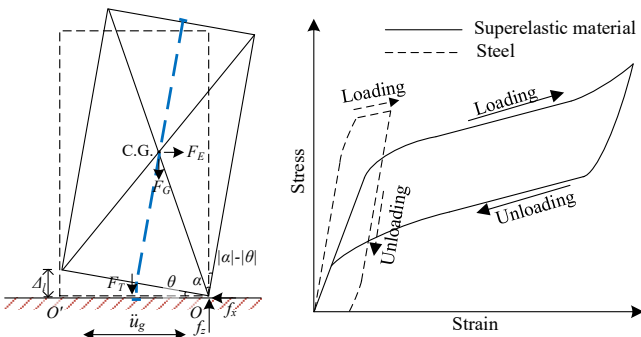
(Murray Grove project building in London, U.K., and the Ibis Hotel East Perth building in Australia)

## DISCUSSION

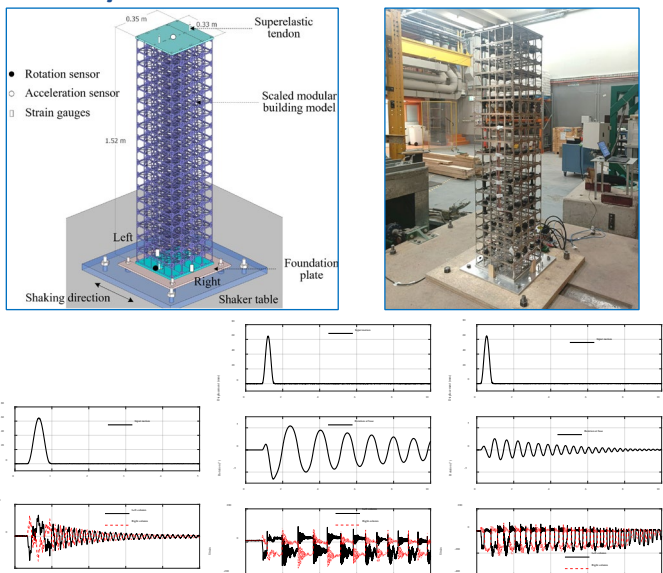
Test results for the fixed-base specimen, free rocking specimen and superelastic tendon restrained specimen testing are presented. The maximum base moment of the three test specimens is 246 Nm, 41 Nm and 158 Nm. The seismic internal force of the model with the superelastic tendon restrained specimen was 36% lower than that of the fixed base model. At the same time, the amount of rotation of the tendon restrained specimen was 61% lower than that of the free rocking specimen. With the tendon restrained specimen, the amount of tensile stress in the columns was lower than the fixed base specimen, but the compression stress was higher, and some limited rocking motions were recorded. The beneficial effects of the superelastic tendon restraints were evident.

## METHODOLOGY

If a steel tendon is used instead, the amount of elongation would be restricted to the yield limit of about 0.2% - 0.4%. In contrast, a tendon made of NiTi alloy can elongate by up to 10% with full recovery potential, making it ideal for facilitating large rocking motion. A scaled-down building model was designed and tested on the shaker table to validate the proposed system of controlled rocking.



## FIGURE/DATA





# Seismic design strategies for controlling torsion-induced seismic demand amplification of plan asymmetric buildings

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## ABSTRACT

The non-symmetric buildings suffer more severe damage during earthquakes than the symmetric counterparts due to torsional behaviours induced by plan asymmetry. The primary purpose of this study is to address appropriate seismic design strategies that can control the amplification of seismic demand induced by torsion. Parametric studies on the single-storey systems have been carried out to investigate how walls with different plan configurations, distribution, size and numbers affect the torsional behaviours. The nonlinear time history analysis for multi-storey buildings is performed to validate the trend observed in single-storey systems. The identification of structural behaviours, rationale and transparency of a viable design strategy, combined with simplicity in application are the central core issues for the purpose of the work.

## INTRODUCTION

The non-symmetric building structures are very common in practical engineering due to the space limit or architectural aesthetics. The non-symmetric buildings will sustain more severe seismic damage than the symmetric counterparts. Although a large number of studies have been carried out focusing on torsional issues, most of them are far from perfect to develop criteria, which are supposed to be simple so that the torsional behaviours can be controlled and checked readily by designers. There is a need to explore more how the configurations of critical lateral resisting elements affect torsional behaviours.

## METHODOLOGY

The single-storey model represented by a single frame-pair model has been widely utilized in investigating the torsional behaviours in the previous studies associated with torsion. Two critical parameters which include the elastic radius ratio ( $b_r$ ) and the eccentricity parameter ( $e_r$ ), are highly related to seismic response amplification induced by torsion. Nonlinear time history analysis will be applied to single-storey systems and multistorey buildings for the investigation of seismic demand induced by torsional issues.

## DISCUSSION

The parametric studies on the influence of walls with different position, size and number and effectiveness of orthogonal walls in controlling torsional behaviours are investigated. A general trend, which shows that low  $b_r$  values will suffer high elastic seismic demand and high  $b_r$  values are effective in controlling the amplification of elastic seismic responses but perform poorly in reducing the inelastic demand, is observed. Both the nonlinear time history analysis for the single-storey and multi-storey buildings shows that the strategies for the use of shorter walls allocated on the flexible edge and the orthogonal walls are beneficial to the control of the seismic demand amplification induced by torsion.

## FIGURE/DATA

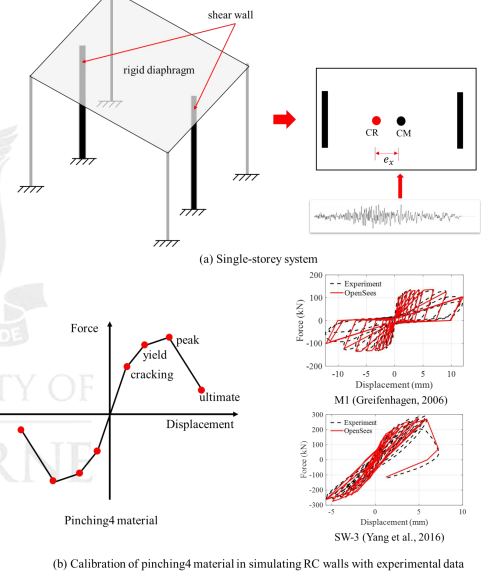


Figure 1 Single-storey systems and numerical models of RC walls

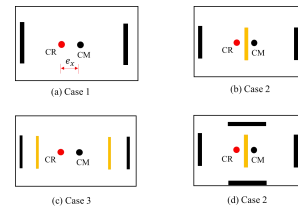


Figure 2 Different design strategies for RC walls

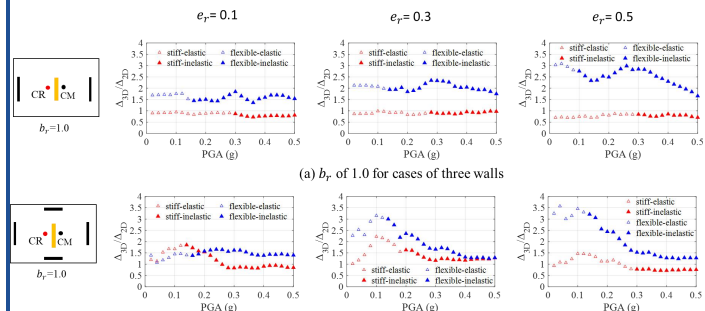


Figure 3 Comparisons of seismic demands for different cases





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**Discipline:** Structural Engineering

## ABSTRACT

Nonlinear analysis has significant safety and economic benefits but is rarely used by practicing engineers in seismic analysis of reinforced concrete buildings mainly due to the demand for higher computational costs and costs related to acquiring input parameters. To fill in this knowledge gap, the authors propose an improved sectional analysis online tool that is easy to use and requires minimal input parameters and computation requirements. The proposed tool is validated with the experimental results of reinforced concrete structural walls.

## INTRODUCTION

The seismic design of structures requires the use of efficient computational methods to accurately predict the seismic demand. Most of the current code of practice uses force-based procedures where design force is determined by reducing the elastic force (determined from elastic analysis) by structure specific response reduction factor. The need for changes in this design approach has been widely recognised and the use of nonlinear analysis has been recommended, for example, Fajfar (2000), and Chopra and Goel (2002). However, nonlinear analysis is rarely used due to higher analysis costs.

## METHODOLOGY

To simplify, expedite, and reduce the cost of nonlinear analysis, this research proposes an optimised sectional analysis-based pushover procedure which is executed using an online tool mounted at “CDASAP.com”. The tool introduced here models the wall cross-section into a number of concrete fibres and reinforcement layers having nonlinear material properties to plot the moment-curvature curve of the section. The curve is converted to nonlinear force-displacement capacity curve which is finally compared with the code response spectrum to determine the inelastic seismic demands.

## DISCUSSION

When the developed procedure/tool is used to analyse the C1 wall specimen (Lu et al., 2015), the analytical and the experimental results (force and displacement capacities) are found to be closely matching with each other (within a 1% difference). Furthermore, the proposed procedure has a clear distinction from other existing methods due to the increased accuracy that is achieved by considering the effect of compression softening and reinforcement buckling effects. A case study which is presented here shows the simplicity, swiftness, and cost efficiency of the developed procedure/tool.

## FIGURE/DATA

1. Input Parameters:

A. Shape of the wall:

B. Concrete Cross-Section:

I. Length of wall,  $L_w$  (mm):

II. Thickness of the wall,  $t_w$  (mm):

C. Disposition of Vertical Reinforcement:

D. Other Input Parameters:

I. Concrete Clear Cover,  $C$  (mm):

II. Diameter of Vertical Reinforcement,  $d_v$  (mm):

III. Diameter of Stirrups,  $d_s$  (mm):

IV. Spacing of Stirrups,  $S_s$  (mm):

V. Yield Strength of Vertical Reinforcement,  $f_{yy}$  (MPa):

VI. Ultimate Strength of Vertical Reinforcement,  $f_{tu}$  (MPa):

VII. Characteristics Compressive Stress,  $f_c$  (MPa):

VIII. Axial load ratio (ALR) or  $N^*$  (kN):

IX. Height of the Wall,  $H$  (m):

X. Plastic Hinge Length ( $L_p$ ):

[GET FORCE DISPLACEMENT PLOT](#)

Figure 1 User interface of the online tool.

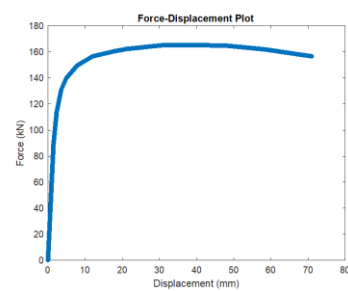


Figure 2 Force-displacement output from the online tool.

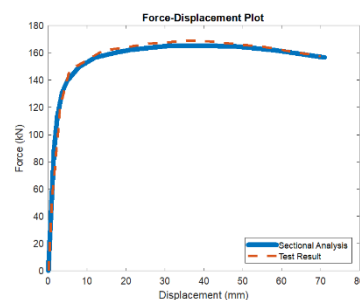


Figure 3 Comparison of the analytical and the test results.





# Seismic Performance of Precast Reinforced Concrete Walls in Low-to-moderate Seismicity Regions: A Preliminary Study

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**Discipline:** Structural Engineering

## ABSTRACT

Precast reinforced concrete load-bearing walls have been widely used in Australian multi-storey buildings. These precast structural walls are typically connected to adjoining walls or foundations by welded stitch plates and grouted dowels. Since there are some uncertainties about the seismic performance of such precast systems, this PhD research was proposed to assess the seismic behaviour of precast walls and buildings with different common detailing practices adopted in Australia. In the preliminary study, a survey was conducted by the authors with practising engineers to understand the industry-standard design practices of precast walls. Based on the survey data, an experimental bond test of grouted dowel connections was designed.

## INTRODUCTION

Compared to traditional cast-in-place RC walls, precast walls can have distinct force-displacement response and failure mechanisms under earthquake actions, depending on the detailing of precast panels and their connections. Previous investigations on this topic are mainly based on laboratory experiments of individual precast elements. It is still challenging to predict the global seismic behaviour of precast walls in multi-storey buildings subject to strong ground motions by a numerical approach. Furthermore, most existing experiments were designed following the 2009 edition of Australian concrete structure code AS3600. However, the latest generation of AS3600:2018 has major updates on the seismic design and detailing of precast load-bearing walls. These changes in design can result in significantly different seismic performance than previously observed. Therefore, more investigations on Australian typical precast wall system are warranted.

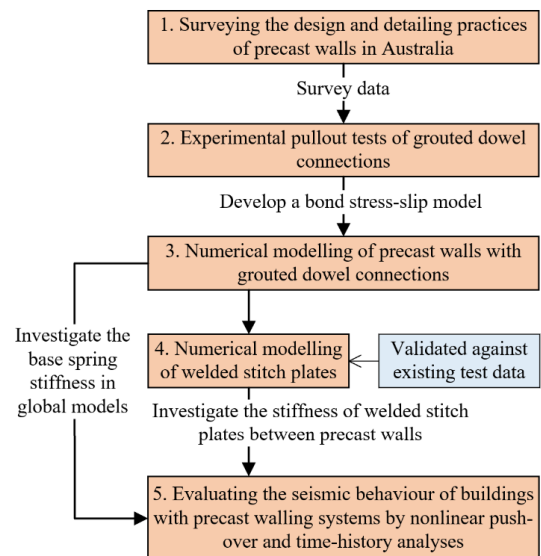
## DISCUSSION

According to the literature review, precast walls designed before 2018 typically failed through the undesired single major cracking and dowel fracturing at the wall base. However, from the survey responses, after the implementation of AS3600:2018, if the precast walls are designed with a ductility factor of more than 1, the walls will be reinforced with two layers of N-grade bars. The reinforcement ratio of dowelled connections is also required to be not less than the wall reinforcement ratio. This change in the reinforcement detailing may shift the weak section from the wall base to other locations in the system (e.g., the top end of base connections or welded stitch plates). However, due to a paucity of an effective modelling approach to simulate the precast walls with grouted dowels and welded stitch plates by computer, the seismic behaviour of these precast walls and buildings has not been sufficiently understood and assessed.

## METHODOLOGY

The research methodology is illustrated in the figure. The authors have conducted a series of questionnaire surveys and interviews on the typical design and detailing practices of Australian precast structural walls. The survey data are used to develop the experimental testing and numerical models in this research. Based on the survey results, the authors designed a laboratory pullout test of grouted dowel connections. The test will be commenced in the coming months and aims to develop a bond stress-slip relation for simulating the grouted dowel connections in precast walls. The modelling of welded stitch plates in the precast system will be calibrated and validated against the experimental data provided in the existing literature. Finally, the global displacement capacity and ductility of buildings using such precast walling systems will be assessed through the non-linear push-over analysis and time-history analysis.

## FIGURE/DATA





# Improve CNN-based crack segmentation performance on imbalanced data using loss functions

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**Discipline:** Structural Engineering

## ABSTRACT

Imbalanced crack datasets diminish the model performance because the number of background pixels dominates the number of crack ones, posing the network to biasedly classify instances to background pixels. This study systematically investigates the impact of 14 loss functions on crack segmentation performance. The Crack Pavement Wild Dataset is used as a case study for the class imbalance issue. Results show that region-based loss functions enable models to converge faster than distribution-based ones. Dice loss and its combination with binary cross entropy and focal loss prove the best performance in mitigating the effect of imbalanced data, improving crack segmentation.

## INTRODUCTION

Crack segmentation has been one of the most vital tasks in crack inspection at pixel level as it provides critical details for crack assessment. However, crack datasets suffer from highly imbalanced problems as the number of non-crack pixels dominate cracks, leading to more false predictions. Most existing studies focus on developing architectures to improve crack segmentation performance. Choosing loss functions is based on a specific case of each study. There has been no comprehensive study on how loss functions and related techniques impact model performance when facing highly imbalanced data problems.

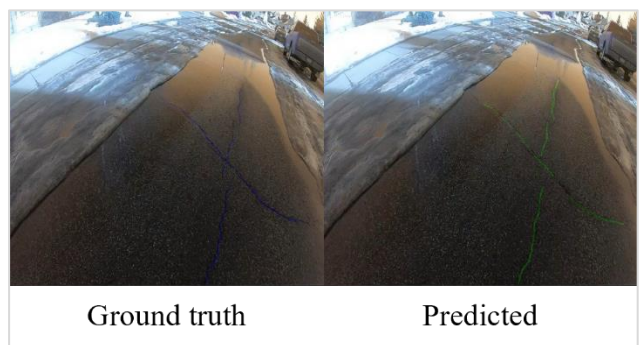
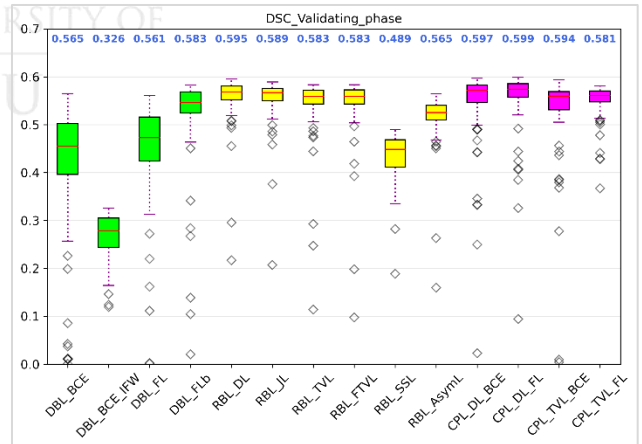
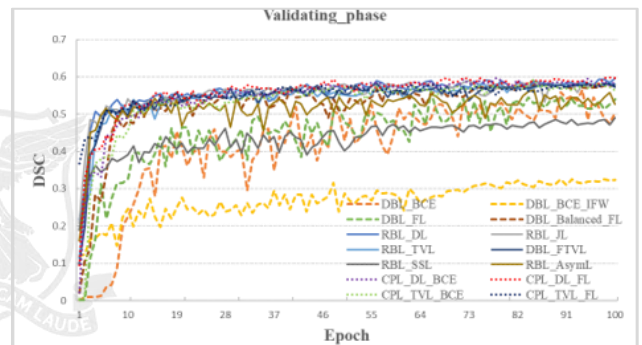
## METHODOLOGY

14 loss functions grouped into three types: distribution-based loss (DBL), region-based loss (RBL), and compound loss (CPL) functions are examined. The baseline model for comparison is the U-net with pre-trained backbone SE\_ResNext. All the models will be trained on a pavement crack dataset name 'Pavement Crack Wild Dataset', in which the imbalance ratio between crack and non-crack pixels is 1: 176. After being trained through 100 epochs, the models' performance is compared using three metrics: Precision, Recall, and Dice Similarity Coefficient.

## DISCUSSION

Overall, the models with RBL functions converge faster than those with DBLs. DBL function models misclassified crack pixels to background pixels more than that of RBLs. The possible reason might be that highly imbalanced data results in biased representation learning of RBL models. Regarding DBL functions, FLb loss outperforms other losses since it guided the model to optimize the loss part of hard samples (crack pixels). BCE\_IFW has the lowest DSC due to the over-prediction of crack pixels. Among RBL functions, DL achieves the best performance, while SS loss performs worst. CPL functions slightly improve crack segmentation compared to single losses.

## FIGURE/DATA





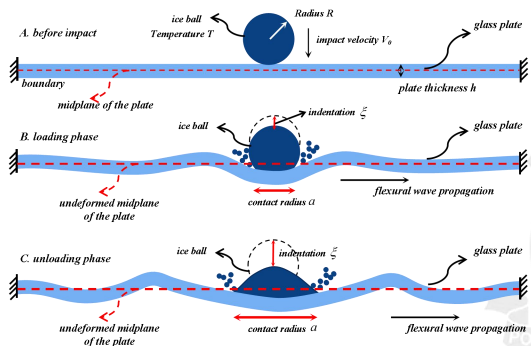
# Flexural Strains in a Toughened Glass Panel generated by Impact of an Ice Sphere

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**Discipline:** Structural Engineering

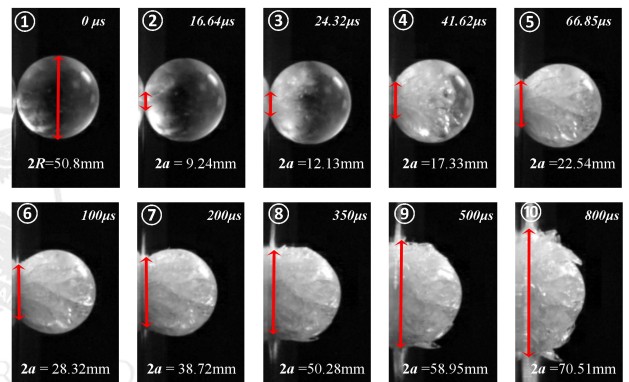
## ABSTRACT

An analytical model for predicting flexural strains on a toughened glass panel generated by the impact of ice is presented. The time-history of the generated surface tensile strains can be used to predict the fracture probability of glass in a projected hailstorm scenario. The strain intensity is found to be insensitive to changes in the panel size, positions of impact, and boundary conditions. The development of flexural strain at the point of contact is controlled purely by the initial generation of waves. The derivation of expressions for predicting maximum strains involved investigations into the change in contact force and radius of the contact area with time. The model has been validated by comparison of the simulated and measured quantities. The model for predicting flexural strain utilizes considerably less computation time than numerical models.

## INTRODUCTION

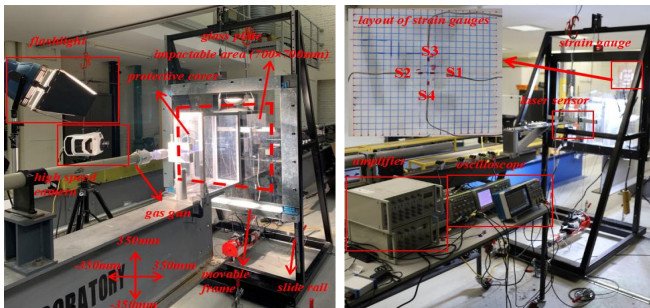


## FIGURE/DATA



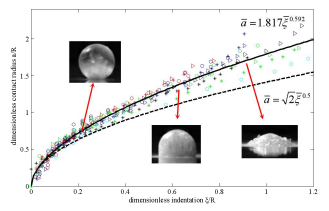
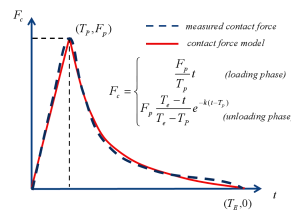
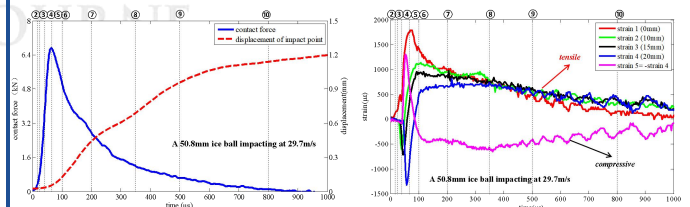
A 50.8mm ice ball impacting at 29.7m/s

## METHODOLOGY

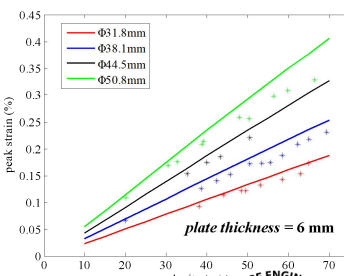
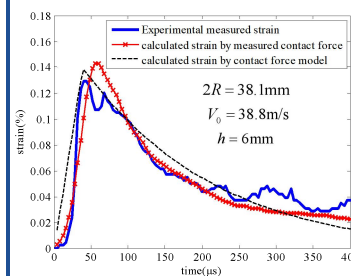


## DISCUSSION

Maximum strains were found to occur within the loading phase which lasts for only about 0.1 ms. The development of the flexural stresses in the glass panel is thus insensitive to the change in size of the panel, position of impact and boundary conditions. Calculation of the flexural stresses require the following algebraic relationships to be developed: (1) contact forcing function of time (2) change in the contact radius with time. Limitations of the proposed methodology have been identified in relation to the idealisation of hail into a spherical specimen of ice, interference by reflected waves in the part of the plate close to its edge and flexibility of the target.



$$\kappa_r(t) = \kappa_\theta(t) = -\frac{F_c(t)}{8\pi D} \left[ \ln \left( \frac{a(t)^2}{4\lambda_p t} \right) - 1 + \gamma \right]$$



# Flow Induced Particle Migration During Concrete Pumping

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**Discipline:** Structural Engineering

## ABSTRACT

The pumpability of concrete is dominated by the formed lubrication layer during pumping, but the independent influences of shear induced particle migration as well as the wall effects on the lubrication layer are far from well-understood. The X-ray CT techniques is applied to estimate particle migration during pumping. And the extent of shear and wall effect induced particle migration is determined independently for the first time. The wall effect is found to plays a major role on the formation of lubrication layer. While the shear induced particle migration depends on the rheology of concrete, which is not significant in concrete with low flowability.

## INTRODUCTION

Concrete pumping is widely applied in the construction site for providing fast, efficient, and economic placement of a freshly mixed concrete for large sized projects. It is believed that a paste rich layer forms near the pipe wall which facilitates the flow of concrete bulk. This so-called lubrication layer is related to the flow induced particle migration. the aim of the work is to determine the extent of shear and wall effect induced particle migration, respectively as well as reveal their relationship with the formation of lubrication layer.

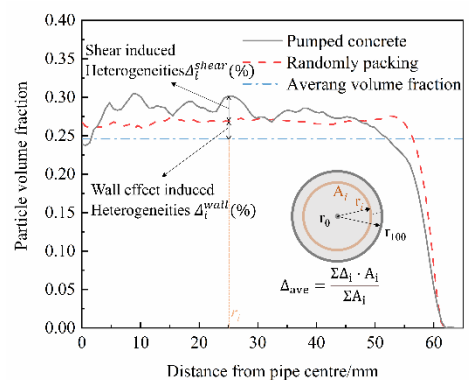
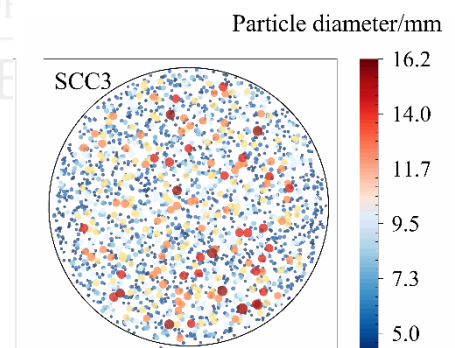
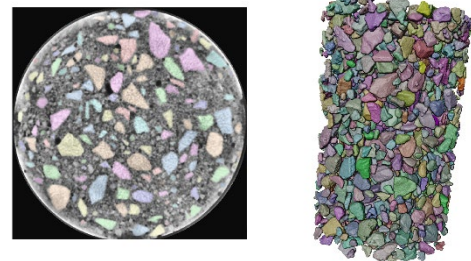
## METHODOLOGY

The 3D tomograph of the particles in pumped concrete was reconstructed by X-ray CT technique. The initial distribution of particle in concrete is represented by a randomly packing model. By analyzing the contrast of the particle distribution before and after pumping, the particle migration in pipe flow could be quantified.

## DISCUSSION

The wall effect induced particle migration depends on the particle size. While the shear induced particle migration is related to the rheology of concrete. In concrete with high viscosity, the low shear gradient is not able to drive the bulk migration of particles in concrete. In concrete with high flowability, the shear induced particle migration is significant, but its extent does not necessarily increase with the flowability of the concrete.

## FIGURE/DATA





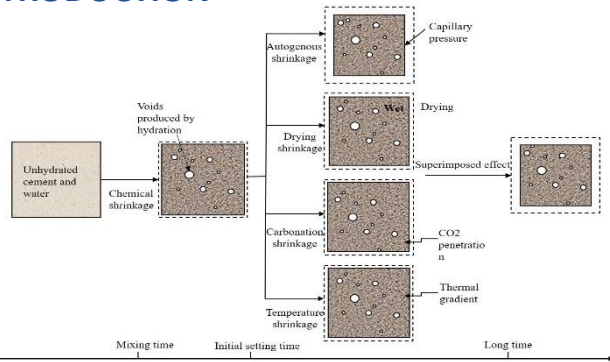
# Effect of Pre-saturated Lightweight Sand on shrinkage of Eco-friendly Lightweight Cementitious Composites

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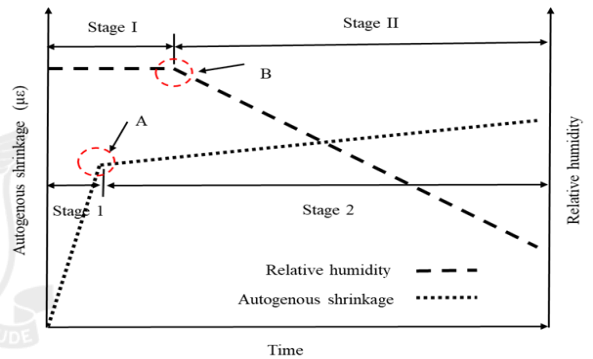
## ABSTRACT

This study developed an eco-friendly lightweight high-strength engineered cementitious composite (ELHECC) using lightweight sand fines (LSF) and fly ash cenospheres. The effects of LSF content and pretreatment methods on shrinkage and micro-mechanism of ELHECC were investigated. Two pretreatment methods – normal pressure immersion and vacuum saturation – were employed. The internal curing effects of treated and untreated LSF were compared. The results showed that increasing the substitution amount of LSF increased the corresponding internal relative humidity, extended the duration of saturated humidity, and subsequently reduced the autogenous shrinkage of ELHECC. The reduction effect of autogenous shrinkage and drying shrinkage after LSF pre-saturation was much greater than without saturation. Furthermore, LSF had superior bonding with the ELHECC matrix, forming a well-integrated sand–matrix interface.

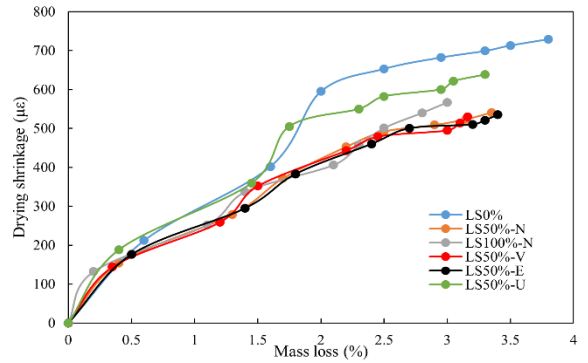
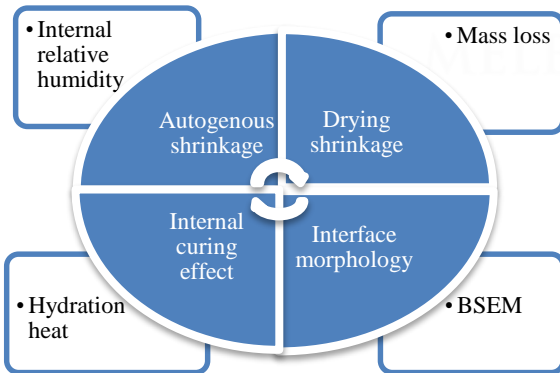
## INTRODUCTION



## FIGURE/DATA

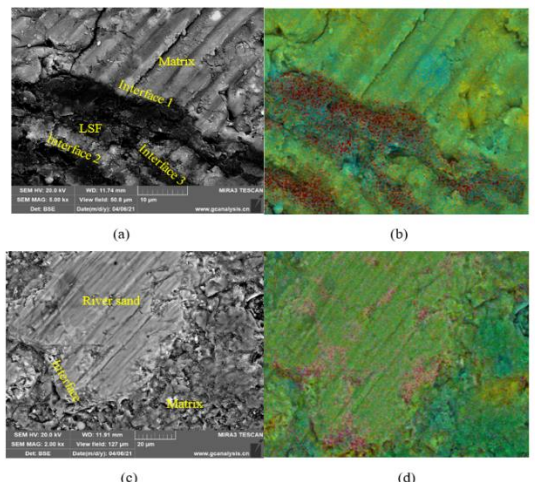


## METHODOLOGY



## DISCUSSION

- Increasing the substitution amount of LSF can increase the corresponding IRH, extend the duration of saturated humidity, and subsequently reduce the autogenous shrinkage of ELHECC.
- The addition of LSF helped to reduce drying shrinkage of ELHECC.
- Pre-saturated LSF delayed the early hydration process of ELHECC.
- Due to high surface roughness and large voids, LSF had good bonding with the substrate, forming a well-integrated sand–matrix interface.



# Assessment of structural performance for bridges utilising structural health monitoring data



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**Discipline:** Structural Engineering

## ABSTRACT

This study presents a structural analysis to evaluate the structural performance of bridges using structural health monitoring (SHM) data. Thereby, the field monitoring strain data obtained from an SHM system installed on a highway bridge is utilised to estimate its structural performance via several key performance indicators (KPI) such as the neutral axis (NA) location, the live load distribution (LLD) factor and the load rating (LR) factor. The analysis results demonstrate that the SHM strain data can provide an insight into the structural behaviour of the bridge subjected to extreme events like heavy truck moving.

## INTRODUCTION

Bridges are one of the most important structures, closing the gaps between different regions and partially accelerating the development of national economy. However, like other structures, structural deficiency and degradation after a long time in service might hinder the safe and efficient usage of bridges. Thus, this study aims to propose a structural assessment framework for bridges, particularly the highway composite bridge, via several key performance indicators (KPI) which are estimated from the in-situ dynamic strain obtained from an SHM project.

## METHODOLOGY

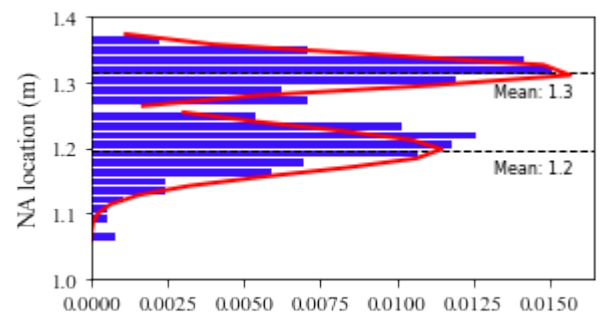
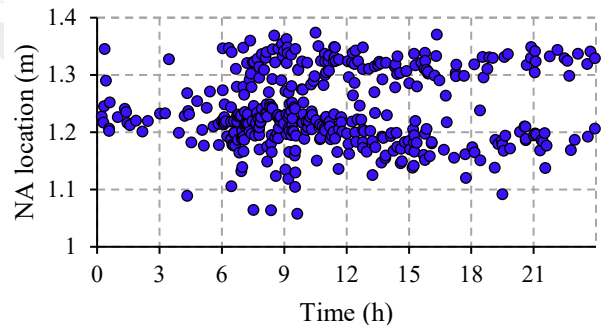
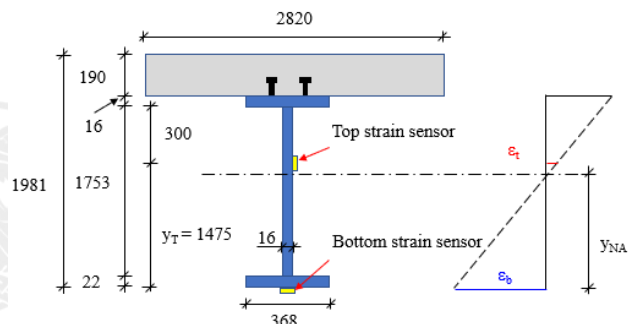
One of important KPIs is the neutral axis (NA) which is employed to estimate the structural performance of the composite steel girder-concrete decking under the repetitive loadings due to heavy vehicles. Based on the locations of sensors attached on the bridge's cross-section, the NA location, symbolised by  $y_{NA}$ , is estimated as follows:

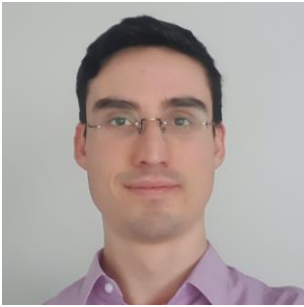
$$y_{NA} = y_T \left( \frac{\varepsilon_b}{\varepsilon_b + \varepsilon_t} \right)$$

## DISCUSSION

The estimation results of NA location at the mid-span of girder G2, which is located right under the heavy traffic lane, show that more vehicle passing events are witnessed from 6AM to 6PM compared to all other times as illustrated via 1-day strain data. In addition, the histogram of NA locations also shows two distinct normal distribution curves, which indicates that there is a shift in the NA location during the 24-hour monitored session. This also indicates that there is a change in the composite action between the concrete and steel components of girder G2, which may imply the occurrence of potential abnormal structural behaviour.

## FIGURE/DATA





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**Supervisor(s):** Prof Tuan Ngo, A. Prof Thai Tai, Dr Phil Christopher  
**Discipline:** Structural Engineering

## ABSTRACT

The embodied energy of the construction materials in our buildings is a substantial contributor to our carbon footprint. Sustainable sourced engineered wood products (EWP) such as cross-laminated timber (CLT) are viable alternatives to conventional concrete and steel, however their inherent natural variability poses a substantial barrier to their wide-spread application. A Monte Carlo simulation (MCS) approach was adopted to capture this inherent variability by defining the material, geometrical and loading parameter as random variables and assigning each a mean, coefficient of variation and distribution. No reliability-based assessment leveraging the full experimental data available in the literature has been published to date. This project will fill that gap, and give designers more confidence to design with CLT in the future.

## INTRODUCTION

The reliability index ( $\beta$ ) is the metric used by design standards to communicate allowable structural risk. Although not included directly in any structural capacity calculations, it governs all the partial resistance factors and load amplification factors that inform those calculations. CLT floors have significant partial resistance factors due to the natural variability of the material that effectively punish the use of these products. By exploring their behaviour from a reliability perspective there is the potential to allow these products to be designed more efficiently, and so be applied more broadly.

## METHODOLOGY

Each material, geometrical and loading parameter was defined as a random variable and assigned a mean, coefficient of variation and distribution. A Monte Carlo simulation (MCS) approach was adopted to randomly combine these random variables and simulate a large number of tests ( $N=10^6$ ), calibrated by a model error factor. The model error factor is used to correct the predicted response to the actual response by using the large experimental test data base available in the literature. Each simulation outputs either a failure or success. Failures are counted and inform the reliability index ( $\beta$ ).

## DISCUSSION

Across the two CLT build-up types (3- and 5-layer) and the two design codes (PRG 320 from N. America and EC 5 from Europe) the MCS with  $N=10^6$  produced reliability index values between 1.49-2.77 (3-layer) and 2.35-3.59 (5-layer). These are lower than the target reliability index of 3.8 (EC5). The relatively small data size of the published CLT bending tests coupled with the difficulty in accurately estimating the material bending strength of the component boards resulted in a model error factor with high variance. This shows a clear need for more test data, and more *good* test data (inclusive of independently measured material properties) to reduce the model error variance.

## FIGURE/DATA

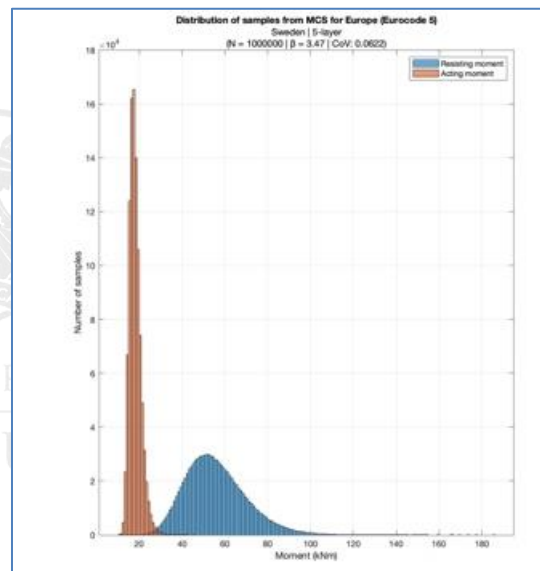


Figure 1: MCS load-resistance histogram

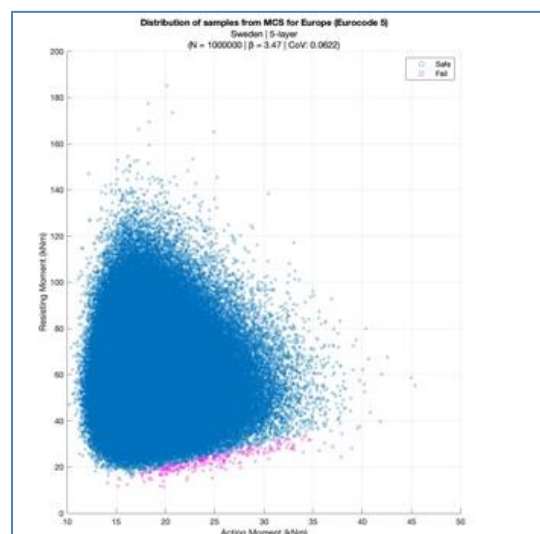


Figure 2: MCS load-resistance scatter plot





# Progressive collapse analysis of steel-concrete composite tall modular buildings

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**Discipline:** Structural Engineering

## ABSTRACT

This research investigates the structural robustness of composite steel-concrete modular high-rise buildings using the alternate load path (ALP) method. Various numerical models were developed for concrete filled steel tube (CFST) columns, semi-rigid frames, and conventional steel buildings under column removal scenarios to verify the validation of the present study. A numerical model of a 10-storey composite modular building was then developed, in which conventional hollow steel section columns were replaced by CFST columns to improve resistance against buckling of columns. To examine the behavior and force transmission mechanism of composite modular buildings under various module removal situations, nonlinear dynamic and nonlinear static pushover analyses was conducted.

## INTRODUCTION

Modular building construction is a type of construction that is increasingly expanding across the globe, which offers efficient and sustainable structures. The construction process includes manufacturing of modular units in a factory-controlled environment, transportation to the construction site, and quick assembly to form the entire building. The major on-site task involves assembly of modules with proper inter-module connections which make up the primary load path for the transfer of forces between modules. Dangerous events such as fire, blast, explosion, and impact can cause severe damage to multi-storey structures, especially if the primary load-bearing components are compromised. In the event of an initial local failure with no alternate load paths (ALP) available, a break in the primary load path can result in progressive collapse.

## METHODOLOGY

The progressive collapse of a modular building has been observed, primarily as a result of the buckling of adjacent columns or due to the failure of horizontal inter-module connections to transfer loads in the event of module or column removal scenarios. To address the drawbacks of typical steel modular structures, concrete filled steel tubular (CFST) columns with improved buckling resistance were proposed. Semi-rigid connections were defined as connector elements in ABAQUS with stiffness and failure parameters for 6 degrees of freedom at each node. Nonlinear dynamic and nonlinear static pushover analyses was conducted to evaluate the most realistic response and the capacity curves, respectively for various module removal scenarios.

## DISCUSSION

- The 10-story composite modular building was determined to be adequately resistant against progressive collapse caused by various module removal scenarios.
- For non-linear static analysis, dynamic amplification factor (DAF) values of 1.65 for corner module and 1.2 for internal and edge module were suggested based on the location of module removal scenarios.
- The study of semi-rigid inter-module connections suggested that rotational degrees of freedom have relatively low impact for non-sway frames under gravity-induced progressive collapse.
- The horizontal inter-module connection/gusset plate resisted and transferred the forces predominantly by vertical shear.

## FIGURE/DATA

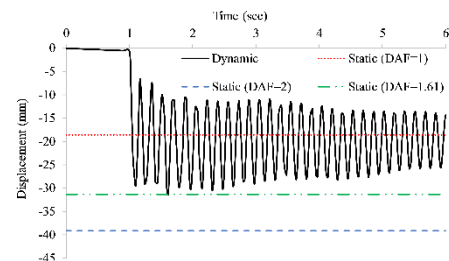


Fig. 1. Displacement response for corner module removal scenario

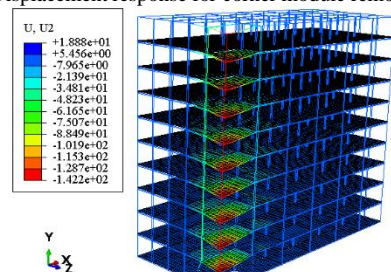


Fig. 2. Buckling of column after corner module removal



# Novel auxetic metamaterials for blast energy absorption

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**Discipline:** Structural Engineering

## ABSTRACT

Structural metamaterials with a negative Poisson's ratio are known as auxetics. Unlike conventional structures, auxetic structures undergo a counterintuitive deformation mechanism; under an axial compression, auxetics show lateral shrinkage and vice-versa. Due to the counterintuitive deformations, auxetics exhibit several superior properties including high specific energy absorption, enhanced shear modulus, indentation resistance, etc. As a result, auxetics have gained popularity in protective engineering applications including the mitigation of blast effects. Therefore, this study developed novel auxetic metamaterials with superior protective performance through a topology optimisation method. The novel auxetics were 3D printed by the fused filament fabrication technique. The performance of the auxetic structures were studied comprehensively through experimental, numeral and theoretical approaches.

## INTRODUCTION

The risk of exposure for various infrastructures, vehicles, aircrafts, naval vessels, etc. to blast load is increasing due to the escalating deliberate and accidental explosions worldwide. As a consequence of different explosions, thousands of people and billions in economic value are lost every year. Therefore, a robust protective system against blast load is essential to ensure the safety of civil and military infrastructures and vehicles alike. Thus, this study proposes an auxetic metamaterial based protective sandwich structure for promising safety of infrastructure against blast loading.

## METHODOLOGY

The unit cell of the novel auxetic structures, named as the hourglass structures (HGS), cross-petal structure (CPS), and braced cross-petal structure (BCPS), were obtained through a topology optimisation method. To examine protective characteristics, bulk scale auxetic structures were designed (Fig 1) and subjected an in-plane compressive load through experimental and numerical approaches. Protective performance was evaluated based on the selected mechanical indicators from the in-plane crushing—peak elastic stress, plateau stress, energy absorption capacity, and densification strain.

## DISCUSSION

The in-plane crushing of the novel auxetic structures uncovered deformation mechanism, stress-strain behaviour, energy absorption capacity, and negative Poisson's ratio. The designed auxetic structures exhibited unique counterintuitive deformation mechanisms to show negative Poisson's ratio (Fig. 2). To examine the effectiveness of the novel auxetics, energy absorption capacities (at the densification strain) of the designed structures were compared with the conventional auxetic designs (Fig. 3). The novel auxetics showed superior energy absorption than the conventional designs. Overall, the designed auxetics showed high potential for blast energy absorption and shock mitigation.

## FIGURE/DATA

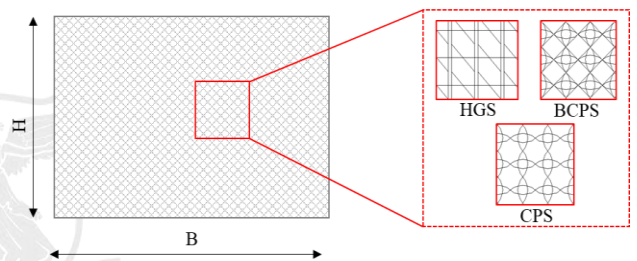


Fig. 1 Representative bulk scale auxetic structure

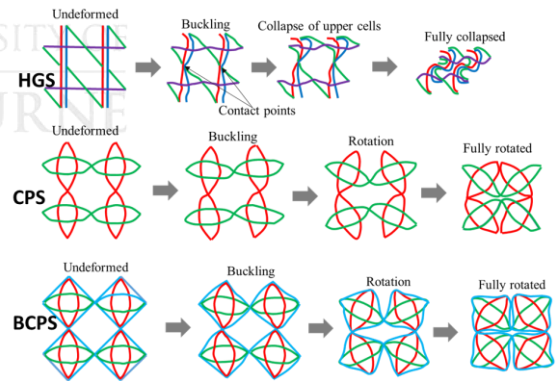


Fig. 2 Deformation mechanism of the novel auxetics

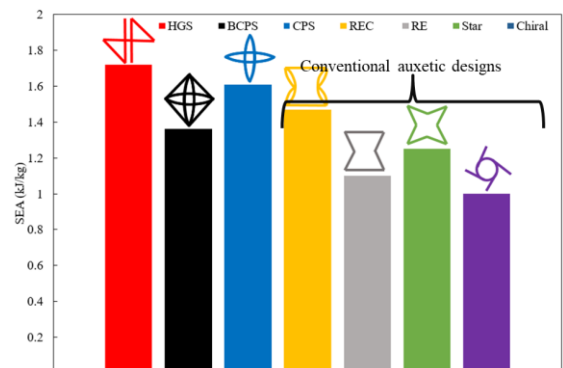


Fig. 3 Comparison of energy absorption with conventional auxetic structures





# Development of molecular to macro scale material testing framework for future hydrogen infrastructure

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**Discipline:** Structural

## ABSTRACT

Hydrogen is emerging as a promising energy vector in the process of attaining net zero targets by 2050 in which both liquid and gaseous hydrogen expect to play uniquely important roles. Infrastructure development of hydrogen storage and transportation requires testing properties of materials to withstand extreme Hydrogen storage conditions such as cryogenic temperatures and failure mechanisms such as hydrogen diffusion and embrittlement. Therefore this study intends to develop a testing framework for mechanical properties of materials integrating molecular, nano-micro and macro scales in hydrogen environments.

## INTRODUCTION

Large scale piping networks and storage vessels, to transport and store gaseous and liquid hydrogen expects to play a critical role in expanding hydrogen usage for multiple sectors such as transportation and power generation in the economy. Hydrogen gas storage tanks are defined as Type I -IV based on the use of metallic and polymeric vessels at room temperature, withstanding pressures in the range of 30 MPa to 70 MPa. Liquid hydrogen with high volumetric energy density compared to gaseous form falls under the domain of cryogenics and is stored at  $-253\text{ }^{\circ}\text{C}$  and 1 atm pressure. Although previous studies have evaluated the properties of materials for gaseous hydrogen storage, a significant gap lies in the domain of liquid hydrogen and no study has developed a comprehensive framework combining mechanical properties from molecular scale to macro scale in hydrogen environments.

## METHODOLOGY

The experimental procedure consists of simulations for molecular scale and lab experiments for nano-microscale and macroscale mechanical testing in both gaseous and liquid hydrogen environments. Molecular dynamics simulations are conducted using LAMMPS software for both classical and reactive forcefields, and nano-micro scale material testings are undertaken using the nano-indenter. Custom built cryostat is used to experiment macroscale properties of materials at cryogenic conditions. In both nano-micro and macroscale experiments samples are tested under four different conditions; 1. Exposing samples to pressurized Hydrogen gas before testing, 2. Exposing samples to liquid Hydrogen before testing, 3. Real time cryogenic testing, and 4. Real time Hydrogen gas exposure testing

## DISCUSSION

This study intends to evaluate the validity of present forcefields for gas and liquid hydrogen simulation, and to develop more accurate simulation environments with lab results. Especially molecular dynamic simulations focus on incorporating the ortho-para effect of hydrogen at different temperatures as ortho-para transition significantly impact the liquefaction process of hydrogen. Nano and micro indentation expects to capture and evaluate the changes in microstructure of materials due to hydrogen exposure at different conditions. Uniquely built cryostat provides the ability to reach cryogenic temperatures to examine the properties of materials at low temperatures such as  $-253\text{ }^{\circ}\text{C}$ . Finally the study intends to develop an integrated model among molecular scale, nano-micro scale and macro scale that can interpret mechanical properties of materials in hydrogen environment.

## FIGURE/DATA

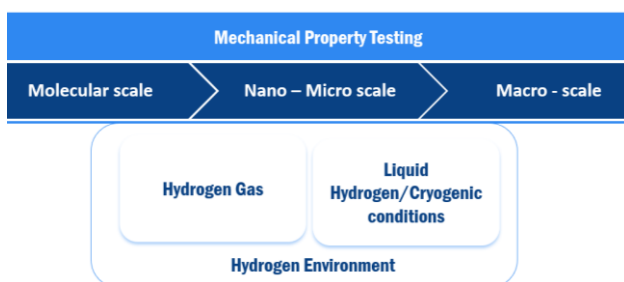


Fig 1: Graphical abstract of the research







# Quantification and verification of microscopic hydrated products of UHPC

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## ABSTRACT

Ultra-High Performance Concrete (UHPC) is essential in the civil engineering construction industry as its superior properties are required to overcome the challenges in civil engineering. Concrete is a heterogeneous material with different scales comprising a combination of cementitious particles and filler materials. The properties and behaviour of concrete at macro and structural levels are influenced by the micro-scale constituents and their properties. However, standard practices such as macro-scale trial and error-based experiments to finalize the desired mix designs and properties cannot capture the relationship to the microstructure. This study provides a novel method to quantify and verify the hydration products of UHPC to link macro properties and structural response of UHPC concrete with the properties of hydration products and unreacted cement particles of cement paste at the microscopic level.

## INTRODUCTION

The major complication in producing concrete with desired properties is the lack of information related to the hydrations and properties of hydrated products at the microscale. Over decades, the scientists have attempted to identify the cement hydration properties at micro-scale by various means and but the development of an unsupervised tool to predict the macro-level mechanical properties by characterizing the hydration at micro-level is in effort. This study provides the foundation to characterize and verify the cement hydration formation at the microscopic level.

## METHODOLOGY

- The research methods to characterize the properties at the micro level were done in the following steps.
- 1-The characterization of micro-level cement hydration by SEM grey levels and EDX element hypermaps using a MATLAB model.
  - 2-Development of a database for unreacted particles and hydrated products
  - 3-Development of AI algorithms and training to identify the microstructural phases/products
  - 4-Statistical verification of cement hydration quantitative data using a virtual cement hydration test platform.
  - 5-Discussion on recommendations.

## DISCUSSION

This framework will be a platform to design UHPC using hydration prediction and small-scale testing, saving money and time. Further, this will enable researchers to understand how microscopic structure relates to the macro response as well as it can be used to modify and develop new UHPC by improving the microstructure and micro/nanoscale additives.

## FIGURE/DATA

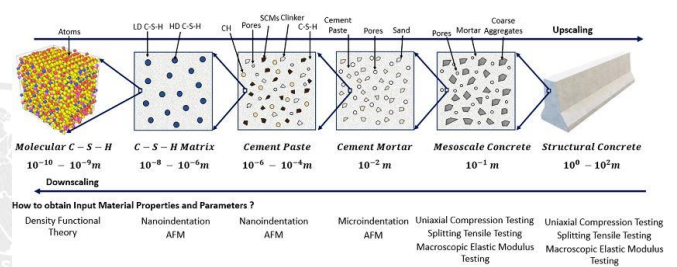


Figure 1: The multi-scale representation of concrete (Thilakarathna et al, 2022)

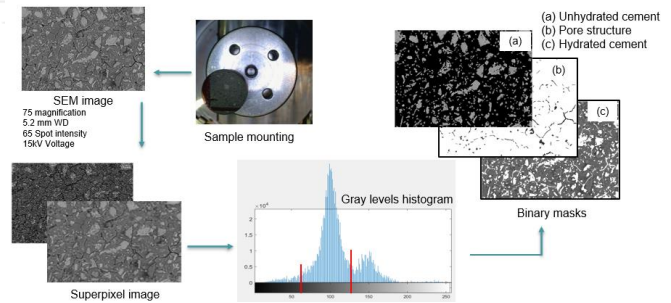


Figure 2: Identification of hydrated, unhydrated and pore phases based on grey scale

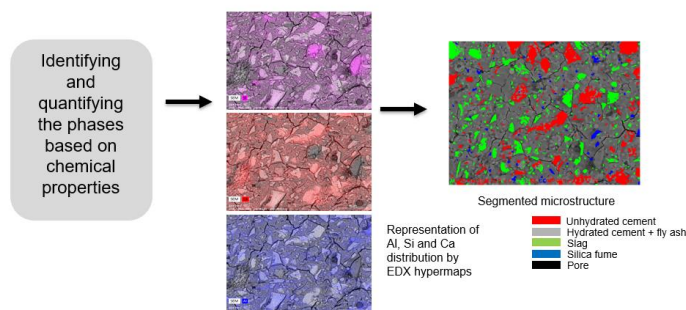


Figure 3: Identification of hydrated and unhydrated phases based on EDX chemical hypermaps





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# TRANSPORT





# Enabling Sustainable Urban Distribution by the Implementation of the Transportation Modeling in the Context of SDGs

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## ABSTRACT

Pandemics change the way people shop, work, entertain and consequently affect the goods distribution patterns, particularly in urban areas. The new coronavirus (COVID-19) pandemic has drastically increased the demand for e-commerce and home deliveries as the most popular modes of deliveries in the last mile. To adapt to the changes to stay resilient and keep the functionality of the freight system, logistics models should deal with the complexity and the level of disturbance brought by pandemics. However, current freight models suffer from a lack of flexibility that keeps them efficient through extreme changes. To improve urban freight resilience in order to keep on track with SDGs, this research aims to model, analyse, and predict the last mile delivery changes in response to pandemics.

## INTRODUCTION

Sustainable urban distribution (SUD) is paramount in achieving sustainable development goals (SDGs) in economic, environmental, and social aspects. SUD aims to ensure accessibility of the transport system to all freight stockholders, to reduce the negative externalities of freight transport, to optimise the use of land that do not have adverse impacts on citizen's life, and to improve economic efficiency.

Several concepts have been proposed to reach SUD, such as physical internet (PI) and city logistics (CL). On the other hand, various types of challenges threaten the achievement of SUD and, consequently, sustainability, such as rapid urbanisation as persistent stresses, pandemics as extreme events and disasters, and newly emerged trends as a result of the dynamic environment of last mile logistics (LML). This research will apply the CL and PI concepts to enhance the flexibility and efficiency of the LML.

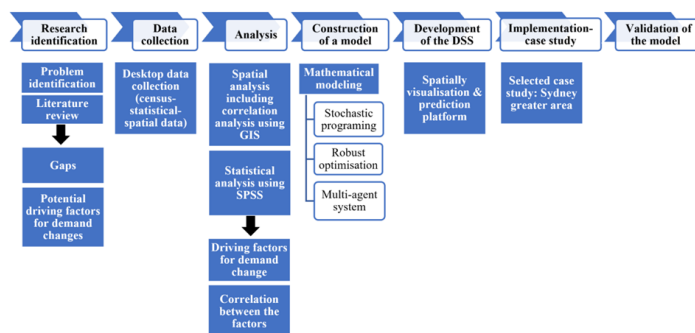
## DISCUSSION

It is well recognised that pandemics and collaborative facilities impact home delivery demand and the urban freight distribution system. Regarding the pandemics, however, a gap exists in the present knowledge of the extent to which pandemics affect e-commerce (how/where/when changes occur?). Current models are not effective to predict such uncertainties, which leads to lacking a robust last-mile distribution model that keeps the customers' satisfaction and timely delivery during and after extreme events. On the other hand, the increase in the use of collaborative facilities in the LML is undeniable. While various stakeholders aim to adapt to the changes to stay resilient and to improve the sustainability of the urban goods distribution system in urban areas, existing models in the logistics domain are not efficient in dealing with the uncertainty of the demand as well as indicating the interaction of existing and newly emerged stakeholders.

## METHODOLOGY

This research aims to design and model the last mile distribution network in line with sustainable urban distribution (SUD) by applying different modelling techniques to tackle the impacts of external uncertainties and newly emerged stakeholders. To support stakeholders' decision-making processes and provide them with optimal courses of action that satisfy the needs of surging e-commerce demand due to pandemics and cope with emerging stakeholders as a consequence of increasing usage of collaborative (open and shared) facilities, a decision support system (DSS) will also be developed. The DSS models, spatially analyses, and predicts changes in urban freight distribution under uncertainty. The DSS also assists logistics authorities/stakeholders to develop a more sustainable and resilient freight distribution network.

## FIGURE/DATA



# Exploring the relationships between travel-based multitasking and activity-travel behaviour



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**Discipline:** Transport

## ABSTRACT

Travel-based multitasking (TBM) (i.e., performing activities while travelling) can influence how we use our time and travel. Individuals may bring daily tasks into the trip and create space for new activities in their schedule. Regarding travel behaviour, TBM may affect how people perceive the time travelling and choose travel modes. Due to TBM, travellers could be willing to travel longer distances in travel modes that enable hands-free travel (e.g., public transport). However, minimal evidence exists regarding TBM impacts on the value of travel time and mode choice. Even less knowledge is available on how TBM affects overall time use. In this context, this research aims to explore the relationships between TBM and activity-travel behaviour, namely: (1) overall time use, (2) value of travel time, and (3) mode choice.

## INTRODUCTION

The viewpoint that travel time is ‘wasted’ has been challenged over recent decades and induced the emergence of a new research field, the so-called ‘travel-based multitasking’ (TBM). TBM has gained traction along with the developments of information and communication technologies (ICTs) (Pawlak, 2020), which transform how we use our time and travel. First, ICTs enable digital activities that can be performed anywhere and anytime, including while we travel. Secondly, ICTs allowed for new mobility services and vehicle automation, increasing hands-free travel options that facilitate TBM. Therefore, TBM can be enhanced and, in turn, affect our time use and travel choices. Due to TBM, travellers can bring tasks into the trip and release time elsewhere for new activities. Also, TBM may influence how they perceive the time travelling and, thus, affect the value of travel time and the choice of travel modes that facilitate TBM (e.g., public transport).

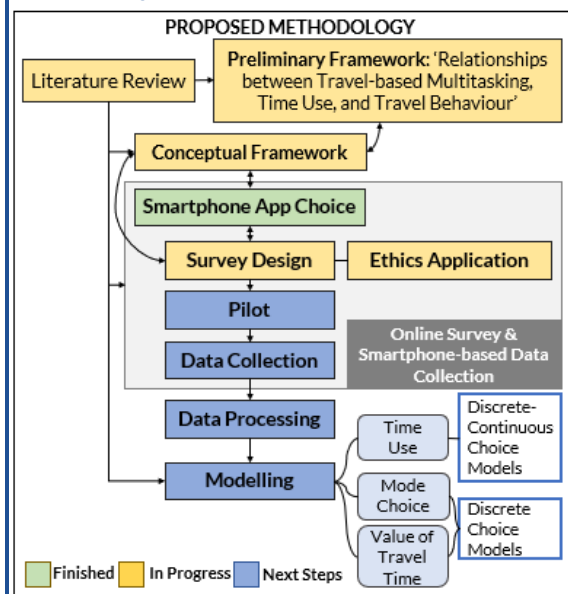
## RESEARCH

There is still very limited evidence on how TBM may impact the valuation of travel time and mode choice. Even less knowledge is available on how the meaningful and productive use of travel time may affect one’s overall time use and daily activity planning. These topics are even more relevant post-pandemic. For example, because public transport ridership has dropped considerably during the pandemic, investing in travel conditions that enhance TBM could help public transport become a more attractive transport option and bring back some of its riders. We need to learn more about the relationships between TBM activity-travel behaviour to support transport policies in these directions. In this sense, this research aims to explore: (1) the relationships between TBM and overall time use, (2) the effects of TBM on the valuation of travel time, and (3) the influence of TBM on mode choice.

## METHODOLOGY

The proposed methodology is illustrated in **Figure 1**. Based on the literature review, we developed a preliminary framework of the TBM effects on overall time use and travel behaviour; also, we identified methodological gaps and selected the most appropriate data collection method for capturing TBM. Therefore, this study implements two data collection approaches. First, we conduct an online survey targeting the adult population living in Greater Melbourne and Geelong. Secondly, we implement a smartphone-based data collection targeting public transport users in the same area of study. Our modelling approaches employ state-of-the-art choice models using the data collected. Discrete-continuous choice models are implemented to explore the relationships between TBM and overall time use, while discrete choice models are implemented to investigate the links between TBM, mode choice, and the value of travel time.

## FIGURE/DATA



**Figure 1.** Proposed Methodology





# Electric vehicle charging styles: A Latent Class Cluster Analysis

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**Discipline:** Transport

## ABSTRACT

The market share of electric vehicles is increasing rapidly. Understanding the charging behaviour of current and prospective EV users is essential for designing policies that positively influence consumers charging behaviour and facilitate EV adoption. In this study, we examined the heterogeneity in charging preferences of current and prospective EV users based on survey data collected from 994 respondents across Australia in mid-2021. We estimated a latent class cluster model considering indicators of charging behaviour as outcomes of interest, and used sociodemographic characteristics, travel needs, and EV adoption status as covariates as class membership predictors. The results point to five segments of consumers with different charging style preferences.

## INTRODUCTION

As electric vehicle charging decisions are more complex than refuelling choices, EV charging decisions may require higher levels of deliberation and cognitive effort from users than refuelling. Models that integrate both the intricacies associated with travel behaviour and EV charging choices rely on assumptions that may not always be behaviourally realistic. It is common to assume that drivers deliberate about charging before/after every trip based on the vehicle's battery state of charge. While this behavioural assumption may represent a segment of users, other segments may base their charging choices on their daily routines or other heuristics. This study aims to identify different EV charging styles and is motivated by the need for a parsimonious representation of consumer heterogeneity in EV charging decision-making that captures different cues and heuristics that individuals may use to guide their charging choices.

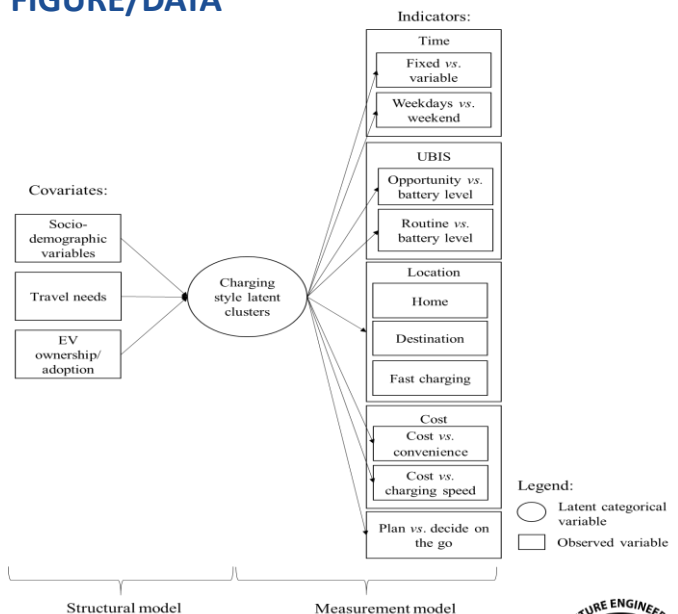
## METHODOLOGY

Latent-class cluster analysis (LCCA) is used to reveal the charging style classes. LCCA groups individuals into latent classes based on differences in a set of observed indicators (charging preferences in this study). To measure indicators of charging preferences, we adopt the idea of UBIS proposed by Franke et al. (2013) for measuring individuals' coping styles related to charging (charging based on routine vs. battery level and charging based on opportunity vs. battery level), while also including four additional dimensions representing user preferences regarding charging: (1) time regularity, (2) location, (3) trade-offs between cost and charging speed, and cost and perceived convenience, and (4) trade-offs between planning for charging or deciding on the go. As covariates, we used individuals' socio-demographic characteristics, travel needs, and technology adopter group (Rogers et al., 2014) to compute probabilities of individual observations belonging to different classes.

## DISCUSSION

We found five distinct charging style classes. The smallest class is indifferent late adopters (8.5%), whose members do not have any preferred charging style, yet. The second smallest class is flexibility seekers (with the highest share of current EV owners), whose charging behaviour of its members is mostly guided by the battery state of charge, charging speed, and convenience. In contrast, predictability seekers plan for charging ahead of time and they follow a routine for charging their vehicle. The two largest classes are cost-sensitive planners (26.7%) and cost-sensitive on-demander (27.5%). Both of these classes have a strong inclination towards monetary savings and home charging. To facilitate EV adoption and supply for charging needs of upcoming EV users there is a need for action in two broad categories; namely, improvement of EV-related knowledge, and providing economical home charging options.

## FIGURE/DATA





# Public Transportation-Based Crowd-Shipping Initiatives: Are Users Willing to Participate? Why Not?

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**Discipline:** Transport

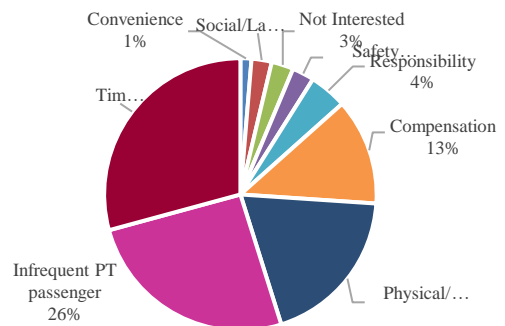
## ABSTRACT

An emerging stream of Crowd-Shipping (CS) solutions focuses on existing momentum in Public Transportation (PT) to ship viable delivery packages by PT passengers. Few studies have explored the package delivery acceptance behavior of passengers engaged in PT-based CS initiatives while passengers' behavioral intention to participate (i.e., engage) is not studied. It is requisite that newly introduced CS platforms explore their potential crowdshippers' behavior on intention to participate and set efficient marketing strategies. Given a survey data collected from 2208 PT passengers in Sydney metropolitan area, this study explores the intention of PT passengers as crowd-shippers to participate in PT-based CS initiatives, as well as prohibiting factors in way of participation.

## INTRODUCTION

This study contributes to the literature on CS with PT passengers by estimating the probability of intention to participate using a binomial logit model developed using a survey data collected from the Sydney metropolitan area in 2022. Results of the model can estimate the initial attractiveness of the initiative for PT passengers and be used in approximating the expected number of registered crowd-shippers. The data collected also includes the reasons for passengers rejecting the initiative, collected through an open-ended question in the survey.

## FIGURE/DATA



## METHODOLOGY

In order to model the intention of PT passengers to participate in the PT-based CS initiative, this research relies on discrete choice models based on random utility maximization (Train, 2009).

Using an inductive thematic analysis, 917 reasons (text responses) for not participating are scrutinized, and the prohibiting factors are identified and categorized. Considering demographic and socio-economic characteristics of the respondents, the study reveals to what degree passengers with different characteristics are sensitive to prohibiting factors.

Variable name (units)	Units	Parameters estimated	Z (P> Z )	95% confidence interval
Female (yes:1, no:0)	1,0	-0.418**	-4.28 (0.000)	-0.610 to -0.227
Young adults (yes:1, no:0)	1,0	0.268**	2.60 (0.027)	0.066 to 0.470
Senior adults (yes:1, no:0)	1,0	-0.403**	-2.27 (0.030)	-0.751 to -0.055
High-income (yes:1, no:0)	1,0	-0.347**	-2.62 (0.014)	-0.607 to -0.870
Full-time employee (yes:1, no:0)	1,0	-0.230**	-1.89 (0.037)	-0.469 to 0.008
Retired (yes:1, no:0)	1,0	-0.527**	-2.71 (0.030)	-0.907 to -0.146
Large household size (yes:1, no:0)	1,0	0.165	1.67 (0.137)	-0.290 to 0.360
PT trip frequency per month	Continuous	-0.012**	-3.20 (0.000)	-0.201 to -0.004
Sustainable role (yes:1, no:0)	1,0	0.537**	3.95 (0.000)	0.270 to 0.804
Locker preference (yes:1, no:0)	1,0	0.793**	6.80 (0.000)	0.565 to 1.021
Locker experience (yes:1, no:0)	1,0	0.514**	4.41 (0.000)	0.286 to 0.742
Medium-volume delivery (yes:1, no:0)	1,0	-0.990**	-5.71 (0.000)	-1.328 to -0.650
High-volume delivery (yes:1, no:0)	1,0	-1.007**	-5.55 (0.002)	-1.363 to -0.652
Constant		0.486 <sup>0</sup>	2.03 (0.082)	0.016 to 0.956
<b>Model fit statistics</b>				
Number of observations		1589		
Log-likelihood at zero betas		-1623.37		
Log-likelihood at convergence		-1283.91		
Pseudo R <sup>2</sup>		0.234		

## DISCUSSION

This research provides several practical insights that can assist in successfully defining, launching, and advertising a new PT-based CS initiative. As a key finding, it is observed that women, full-time employees, elderly, retirees, and low-income PT passengers hardly participate, while the youth, individuals with a positive attitude towards sustainable freight initiatives, and those who experienced working with parcel lockers would participate with a higher probability. Moreover, it is observed that factors relating to time availability/flexibility and physical health condition of passengers are much more important than the compensation level for passengers to accept to participate in PT-based CS initiatives.

**Variable definition:**  
**Female:** Women  
**Young adults:** Individuals aged less than 40  
**Middle-aged adults:** Individuals aged between 40 to 60  
**Senior adults:** Individuals aged more than 60  
**Low income:** Individuals with an income less than 30k AUD per year  
**Medium income:** Individuals with an income between 30k AUD to 90k AUD per year  
**High income:** Individuals with an income more than 90k AUD per year  
**Full-time employee:** Individuals working full time  
**Part-time employee:** Individuals working part time  
**Unemployed:** Unemployed individuals  
**Retired:** Individuals who are retired  
**Disable:** Individuals with disability  
**Small household size:** Individuals living in households with maximum 2 members  
**Medium household size:** Individuals living in households with 3 or 4 members  
**Large household size:** Individuals living in households more than 4 members  
**PT trip frequency per month:** An average number of PT trips per month  
**Sustainable role:** Individuals supporting sustainable urban freight initiatives  
**Locker preference:** Individuals not having an opposition to contact with parcel locker facilities  
**Locker experience:** Individuals having has working experience with parcel lockers  
**Low-volume delivery:** Individuals having less than 5 deliveries per year  
**Medium-volume delivery:** Individuals having between 5 to 20 deliveries per year  
**High-volume delivery:** Individuals having more than 20 deliveries per year  
**Apartment dwellers:** Individuals living in an apartment  
**House residents:** Individuals living in a house





# A graph neural network model for predicting citywide short-term crash risk based on administrative geographic units

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**Discipline:** Transport

## ABSTRACT

Graph neural networks have shown outstanding results in predicting citywide short-term crash risk. However, the existing approaches are constrained by a gridded data representation of space. To address the spatial limitation derived from gridded data, gated diffusion graph neural network (GDNet) model is proposed to forecast locations where crashes are likely to occur in a future time. The model is validated for the City of Melbourne over a period of two years, considering two alternative geographic units (Statistical Area Level 1 and grid). The results show that the GDNet outperforms the baseline methods. In terms of geographic units, the SA1-based GDNet performed better than its grid counterpart.

## INTRODUCTION

The predictive hotspot mapping of short-term crash risk aims to forecast locations where crashes are likely to occur in a future time window. Identifying locations with a higher probability of crash occurrence provides valuable insights for implementing preventive strategies to improve road safety and can contribute to a more effective allocation of city resources. Deep learning (DL) and graph neural network (GNN) models have shown exceptional results compared with traditional statistical methods to predict citywide short-term crash risk. However, the existing approaches are constrained by the need to represent spatial data as grids, which imposes limitations on the analysis and use of the model output, including misrepresenting the natural and built environment. Therefore, a GNN model based on the irregular spatial representation of space would improve crash risk prediction and create real-world application opportunities.

## DISCUSSION

In contrast to previous GNN applications to crash risk prediction, the GDNet considers the historical occurrence of crash events as the only data input and is not constrained by a gridded representation of space. Both characteristics greatly increase the applicability of our model in a range of real-world scenarios. In terms of geographic units, the SA1-based GDNet performs better than its grid counterpart, which is explained by two main factors: the underlying information associated with the definition of the boundaries of SA1 units and network properties. As a result, the SA1-based GDNet is able to identify crash risk in low-density areas with a relatively low frequency of crashes, which would likely be missed if a grid unit is used. In conclusion, this study shows that using predefined spatial units based on governmental administrative structures improves crash risk prediction and facilitates real-world applications.

## METHODOLOGY

The purpose of a citywide short-term crash risk prediction is to generate probability distributions to indicate locations most likely to observe crash occurrences in the near future. We consider the prediction of crash risk to be a predictive hotspot mapping problem, which is addressed using a GNN model (gated diffusion graph neural network). The objective of the model is to learn a mapping function  $F$  that indicates where crashes are more likely to occur in a future time step  $t$ . Based on a network representation of geographic units, crashes are aggregated on a defined time scale (i.e., daily), and the crash tally is stored as an attribute of the graph nodes. The prediction of crash risk based on a set of historical graph signals  $x_M$  is defined as:

$$y_t = F(x_{t-1} \dots x_{t-M} | G)$$

where  $x_{t-M} \in \mathbb{R}^N$  is a graph signal defined by a  $M$  time window,  $G$  is a structured graph and  $y_t \in \mathbb{R}^N$  is the estimated graph signal at the time step  $t$ .

## FIGURE/DATA

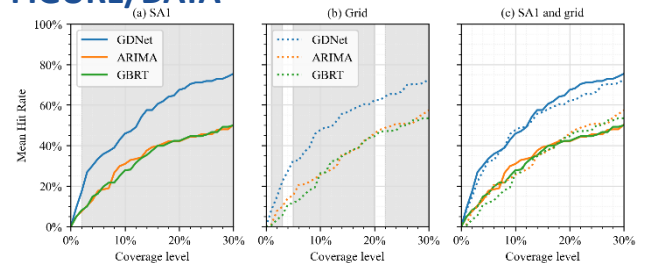


Fig 1: Mean hit rate against coverage level for GDNet and baseline methods based on SA1 and grid units.

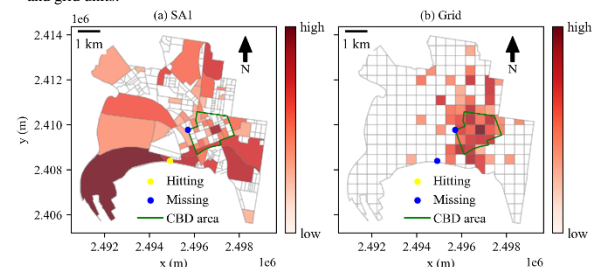


Fig 2: Predictive crash risk for a random day at a 20% coverage level based on the two geographic units.





# AuDL: A Deep Learning Method for Listening to the Traffic Sounds

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**Discipline:** Infrastructure Engineering

## ABSTRACT

The sensors employed in intelligent transportation systems operate based on either touching (e.g.: inductive loop detectors) or watching (e.g.: traffic monitoring cameras) the environment. In this research, we added a new sense, i.e. listening to the environment and responding in turn. In contrast to other technologies, the sound could be used to determine different features of the vehicles, even in blind spots of the other sensor. We developed an model to detect high-priority vehicles and respond to their demands immediately. Our proposed DNN model detects and categorizes vehicles reliably, even in presence of different environmental noises.

## INTRODUCTION

Input data has an indispensable role in ITS management. Not only do other currently employed sensors suffer from several drawbacks, but also hearing-impaired road users or pedestrians need to detect and respond to emergency vehicles immediately. Previous methods mainly relied on multiple numbers of microphones, computationally expensive methods, require neat data (low environmental noise) or were not generalizable to every country. Our method performs well considering the conditions mentioned above.

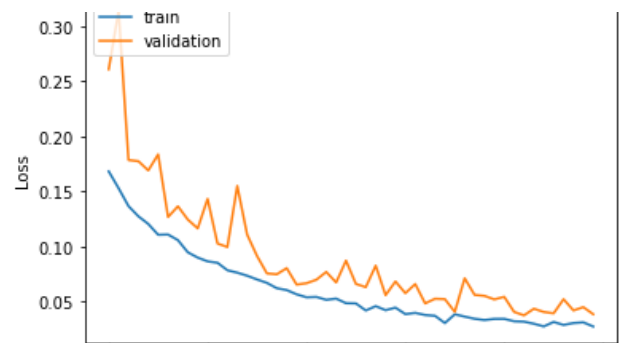
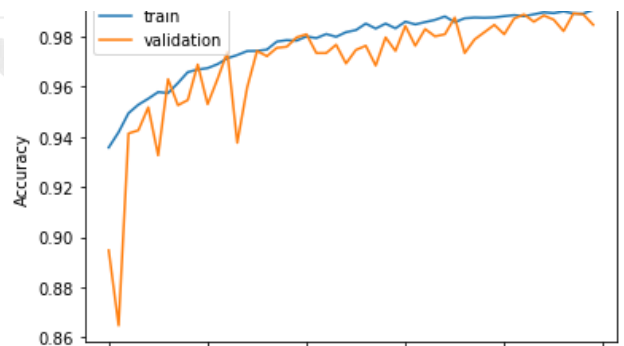
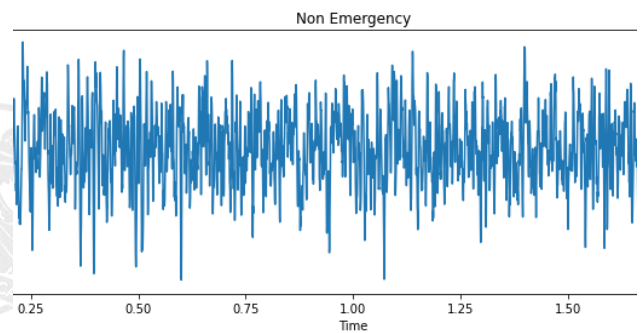
## METHODOLOGY

A dataset consisting of the sound of both normal and emergency vehicles in presence of different types of environmental noises was considered. Firstly, the role of applying different sample rates on data entropy was analyzed. Then, to extract the features from the audio signal, 1D-CNN was utilized. The model was then modified in terms of model layer configuration to reach the best performance regarding the input data. Also, the performance of the model in presence of noise was evaluated.

## DISCUSSION

The result of the research shows the effectiveness of DNN in extracting different signal features in the presence of unwanted and adverse sound data. Compared to the vanilla ANN model and similar methods, it proved to fast and effectively distinguish emergency vehicles. This method can detect emergency vehicles in just 250ms with an accuracy of more than 98%. The next step in our research is to extend our model to detect the distance and direction of movement of the vehicles.

## FIGURE/DATA







# Shipment Matching and Pricing in Intermodal Transportation Considering Disruptions

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**Discipline:** Transport

## ABSTRACT

This study develops a model to help a service provider (i.e. freight forwarder – FF) to match delivery requests from customers (i.e. contractual and on-spot shippers) with available services (i.e. road only or road-rail) and determine the prices charged in the context of intermodal transport by taking into account the disruption information. The FF needs to guarantee the freight picked-up and delivered within specified time windows. Three types of disruption are considered: rail, road, and hub disruption. The disruption may affect freight delivery time and further the real value of each on-spot shipper's willingness to pay (WTP) as the maximum price that FF can charge. The model is tested on a hypothetical network, and the results indicate that the disruption has resulted in different prices for different requests.

## INTRODUCTION

Intermodal transport emphasizes the integration of various modes by using standard loading units. The delivery for each request is carefully planned to maximize the benefits for both FF and shippers. For example, FF wishes to maximize its profit by selecting a service and charging as much as it can subject to the shippers' WTP while minimizing delivery costs. Taking into account potential disruption to intermodal transport planning is also critical to ensuring the FF's performance visibility and reliability. This is because disruption may result in additional delivery time and cost.

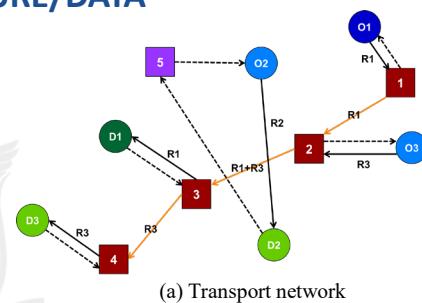
## METHODOLOGY

A single-objective mixed-integer programming model is built to determine the allocation of transportation services to each request along with the price charged. The goal is to maximize the profit of the FF. The model is implemented to a hypothetical dataset (a network consisting of 3 origins, 4 hubs, 1 FF depot, and 3 receivers) and solved in Python 3.10 using the GUROBI solver. The model is run under four scenarios: a) Normal without disruption; b) Rail disruption; c) Road disruption; d) Hub disruption. The occurrence of disruption as well as other parameters are known.

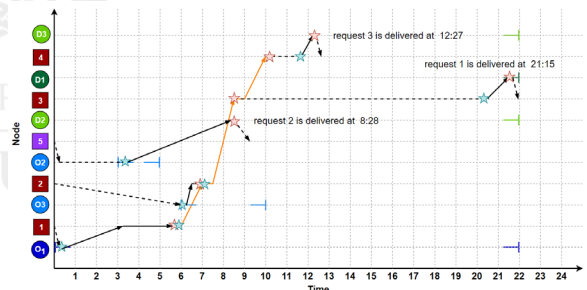
## DISCUSSION

Disruption has resulted in different prices for various requests. Although the contract request is delivered at the same time under different disruption types, the price is different because the route taken is different, as is the distance travelled. The price for the on-the-spot request decreases as the delivery time increases. Regardless of the type of disruption, all requests are completed within the time windows. The FF sacrificed its benefit for on-time delivery. Clearly, the disruption affects the profitability of FF. Therefore, future study will focus on advanced pricing and allocation strategies to prevent disruption-induced profit loss.

## FIGURE/DATA



(a) Transport network



(b) Space-time diagram

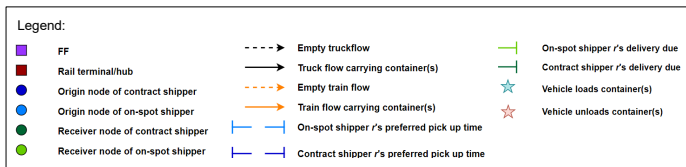


Figure 1. Solution for the normal scenario

Table 2. Solutions for all scenarios

Scenario	R1		R2		R3		FF's Revenue	FF's Cost	FF's Profit
	T	P	T	P	T	P			
Normal	21:15	330	8:28	311.8	12:27	309.6	951.3	922.7	28.7
Rail Disruption	22:00	330	8:28	311.8	13:06	297.1	938.9	922.7	16.3
Road Disruption	22:00	260	8:28	311.8	12:27	309.6	881.3	857.1	24.3
Hub Disruption	22:00	635	8:28	311.8	12:27	309.6	1256.3	1339.1	-82.7

R: Request ; T: Delivered time ; P: Price charged





# Abnormality Detection in Urban Traffic Data: A Review of the Literature

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## ABSTRACT

Anomalous data is called to a data sample or a sequence of data that significantly differs from the others. Accurately and on-time detection of anomalies is crucial for system managers since it may convey important information to them. In this paper, we review the literature of anomaly detection in urban traffic data to find the most recent methodologies in this field. Studies are analyzed regarding anomaly type, data type, and methodology. Different types of anomalies, data collectors, spatiotemporal scopes, and detection methods are categorized. Based on the findings, accidents and city-wide events like festivals are mostly investigated as anomalies using loop detector (LD), and trajectory data (GPS data).

## INTRODUCTION

Nowadays, with the massive usage of different data collection platforms, anomaly detection has attracted more attention. Traffic data is mostly collected within the city exploiting connected vehicles, loop detectors, microwave detectors, and radar sensors. Since the traffic data include spatiotemporal scopes, it is a controversial task to find abnormalities among the vast multi-dimensional available information.

In this paper, we review the literature to answer these three questions: 1) what types of anomalies are defined previously in the area of traffic engineering. 2) what types of data are mostly exploited in the literature to find anomalies. And 3) what are the most recent methods for anomaly detection. We investigated the literature by a search method regarding these three questions. A summary of the findings is reported in this research.

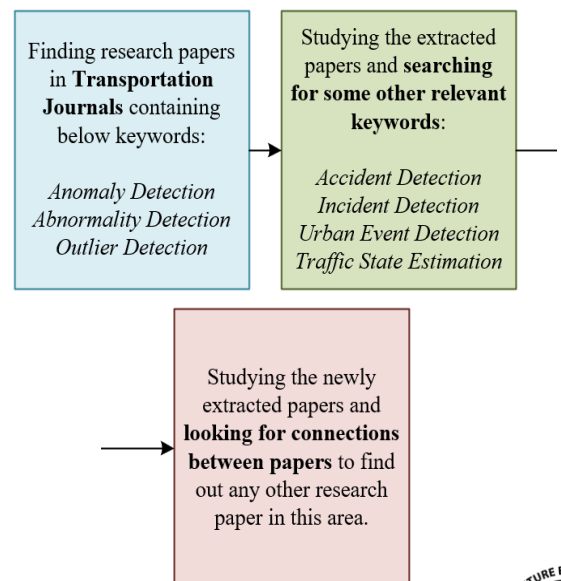
## DISCUSSION

Results found by this paper indicate that accidents and city-wide events are the most investigated anomalies in the previous studies. Loop detectors and GPS sensors are the main platforms for data collection in this field. Recently, GPS data is mostly used to capture city dynamics for detecting city-wide events, however, loop detector data is exploited to monitor a single road segment for detecting short-time anomalies like accidents. Furthermore, the accident detection problem is mostly formulated as a classification problem in the literature, but other types of anomalies are entirely detected by unsupervised approaches like clustering algorithms and density-based thresholds.

## METHODOLOGY

A search method is adopted in this paper to find the most relevant research papers to our topic which is "Anomaly Detection". Figure 1 shows our scheme to dig into the literature and select the desired articles. Primarily, we searched for research papers containing some keywords, indicated in Figure 1, in their titles, abstracts, or index terms. At this stage, we decided to exclude research papers related to surveillance cameras or trajectory anomaly detection as these areas are very different from the rest in terms of methodology and problem definition. Moreover, it should be noted that recently published papers, specifically after 2017, were our target for investigation. After choosing many relative research papers and analysing them, some new keywords were again obtained. We also explored the literature according to these new keywords to not miss any research paper linked to our topic. In the last step, we analysed the connections between the articles.

## FIGURE/DATA





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## ABSTRACT

Effective long-term forecasting of traffic flow has many applications. Existing research focuses on prediction for up to 1 day, yet there is an emerging demand for a longer forecasting horizon. This paper evaluates promising deep-learning methods with real-world data on long-term forecasting up to 14 days ahead. In addition, the impact of the shrinking size of training data is investigated. Results indicate that Informer outperforms RNN, LSTM, and GRU, especially when the forecasting span is extended. Besides, 2 months of training data seem enough for it to achieve decent performance.

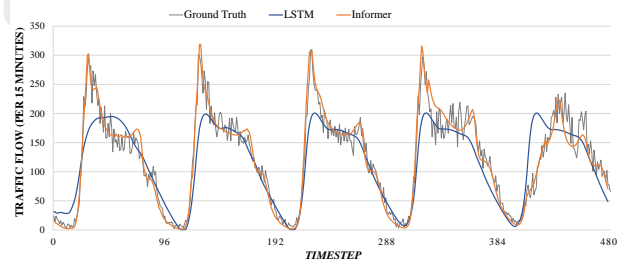
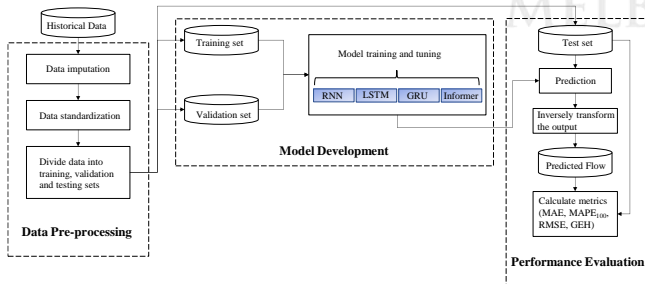
## INTRODUCTION

Traffic flow forecasting can be used for tasks ranging from road condition control to travel planning. Research applying deep-learning methods to traffic forecasting is mainly evaluated over a 5-minutes to 24-hours prediction window. This work investigates the performance of a spectrum of Sequence to Sequence deep-learning methods (RNN, LSTM, GRU and Informer) on a longer term (up to 14 days) traffic flow forecasting in different scenarios, including the increased forecasting horizon and the reduced size of the training data.

## FIGURE/DATA

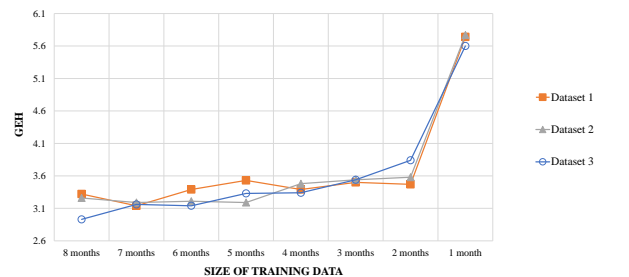
Dataset No.	Forecasting Horizon	Metric	RNN	LSTM	GRU	Informer
1	day	MAE	26.4	21.93	22.37	15.62
		RMSE	39.44	32.65	33.26	25.19
		MAPE <sub>100</sub>	18.53%	15.56%	15.48%	11.72%
		GEH	4.73	4.00	4.08	2.67
3	7 days	MAE	63.4	29.1	53.04	17.14
		RMSE	75.16	42.24	63.71	28.43
		MAPE <sub>100</sub>	30.59%	18.30%	28.64%	12.58%
		GEH	12.45	5.32	10.42	2.9
	14 days	MAE	63.2	28.43	29.3	16.57
		RMSE	75.22	41.45	42.51	26.22
		MAPE <sub>100</sub>	30.32%	18.02%	18.88%	12.29%
		GEH	12.35	5.15	5.31	2.93

## METHODOLOGY



## DISCUSSION

A key factor contributing to the improved forecasting capacity of Informer is its adopted self-attention mechanism, which enables the model to analyze the entire input sequence and utilize the most relevant information, regardless of the length of the data sequence. Another main reason can be, for Informer, the whole prediction sequence is generated at once with its proposed generative decoding process, avoiding error accumulation from the recursive decoding process.





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# ENERGY



# Safety investigation of hydrogen energy storage systems using quantitative risk assessment



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## ABSTRACT

Hydrogen energy systems (HES) are expected to play a key role in supporting the net zero energy transition. This paper aims to study the safety of hydrogen storage systems by conducting a quantitative risk assessment (QRA) to investigate the effect of hydrogen storage systems design parameters such as storage size, mass flow rate, storage pressure and storage temperature. In certain cases of large storage volume or high storage pressure, risk mitigation measures must be implemented since the risk of the hydrogen storage system is unacceptable. The study highlights the significance of risk analysis and the importance of considering costs associated with risk mitigation in the design of hydrogen storage system.

## INTRODUCTION

The use of hydrogen as a clean fuel as well as a long-term flexible energy storage option for backing up intermittent renewable sources has been rapidly increasing. Nevertheless, hydrogen also has numerous safety issues related to hydrogen embrittlement, relatively wide flammability limits and low minimum ignition energy. Current HES designs are primarily driven by cost considerations to achieve economic benefits. This is the first study that quantifies the risk of HES into numerical estimation.

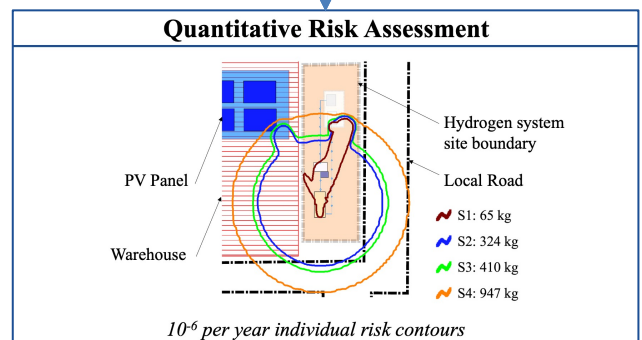
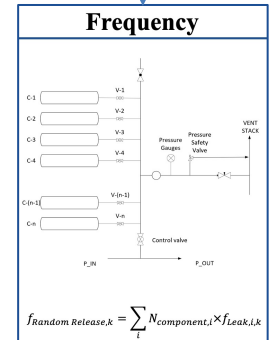
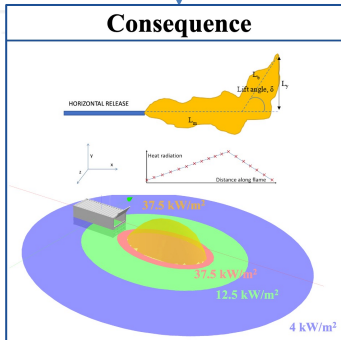
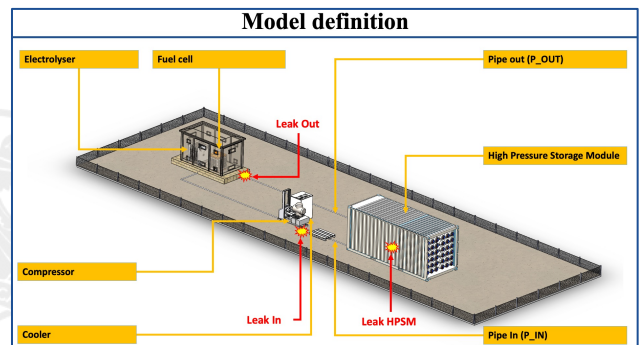
## METHODOLOGY

The QRA procedure, which includes data collection and hazard identification, frequency analysis, consequence analysis and risk analysis, was carried out for the hydrogen storage system presented in a previous study. In the consequence analysis, the Millers model and TNO multi-energy were used to model the jet fire and explosion hazards, respectively. In the frequency analysis, total system leakage frequencies were calculated based on the hydrogen data from Sandia National Laboratories and the piping and instrumentation diagram. SAFETI v8.6 was used to automate the QRA calculation process.

## DISCUSSION

The results revealed that the system parameters such as storage capacity and pressure play a vital impact on the safety of the system. The consequences (radiation, overpressure, impacted distance) of system failure (leakage, rupture) increase as the storage capacity and storage pressure increase. The calculated risk results indicated that for HES with a large storage capacity or high storage pressure, the  $10^{-6}$  risk contours cannot be contained within the hydrogen storage system boundary. This poses an unacceptable risk to third parties outside of the HES boundary, which indicates that risk mitigation measures must be implemented.

## FIGURE/DATA



# Decarbonising the Residential Building Sector: A Multi-Scale Life-Cycle Approach



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## ABSTRACT

Although there have been continuing efforts to reduce the residential sector's carbon footprint, the effects of embodied carbon have only recently been considered; the importance of which for climate mitigation is now being more widely recognised. Developing effective strategies to decarbonise the sector is very challenging particularly because the diversity of the housing stock, the number and heterogeneity of its stakeholders – such as households, developers, intermediaries, and policy makers – and the dynamic nature of their decisions and actions can lead to many possible scenario outcomes. The present study aims to develop a typology-based hybrid approach by integrating a bottom-up housing stock operational carbon assessment with embodied carbon assessment and an agent-based model that would account for actor-decision dynamics within the residential sector.

## INTRODUCTION

The Australian building and construction sector accounts for roughly a quarter of CO<sub>2</sub> emissions yearly and having a significantly higher GHG emissions per capita compared to other developed nations. Most building carbon footprint data as well as their corresponding policy strategies only incorporate the operational phase, however the interest towards incorporating the entire building life cycle has been growing.

For the residential sector, it is observed that the rate of integrating green building practices is slower compared to commercial buildings because of institutional stakeholders, particularly on the side of the households and industry players. For households, it is difficult to project future scenarios because of their heterogeneity in actions taken such as purchasing energy efficient equipment and overall energy use, thus it is also difficult to decide on the appropriate intervention schemes towards decarbonisation.

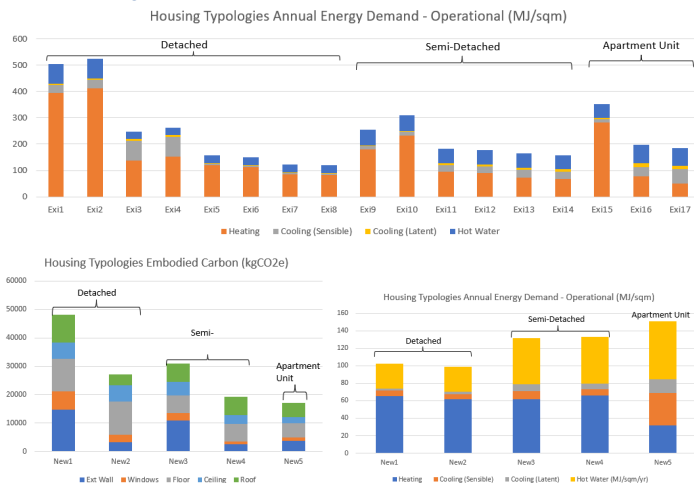
## METHODOLOGY

This research will involve three main methodological concepts; incorporation of embodied and operating impacts within the building simulation model framework, using agent-based modelling (ABM) to analyse household decisions and how they impact carbon reduction scenarios, and determining the corresponding decarbonization pathways needed as well as roles of key stakeholders given the heterogeneity of households and whole-life carbon assessment. A life-cycle based typology assessment of residential building stock would first be done to establish a more accurate carbon footprint baseline at both local government area and state scale. This would be set to a time horizon from 2020-2050, which can be used for initial scenario analysis and be compared to set carbon targets. Household typology attributes would be incorporated with the housing characteristics to develop agent clusters, accounting for aggregate behaviour from individual actions.

## DISCUSSION

The 20 unique housing representatives developed for the whole-life carbon analysis are based on the following attributes; NatHERS rating, housing type, and construction wall type. NatHERS rating would incorporate operating dwelling energy performance with respect to the construction year, considering the minimum rating policies set for new construction over time. The initial set of typologies would serve as basis in creating typologies for new and renovation housing stock as the baseline extends to 2050. From the initial baseline residential building stock typology projections, most of the operating energy demand would stem from heating loads, with the share of cooling loads increasing as houses are built more energy efficient. Embodied carbon was only accounted in new construction as this is already emitted in existing housing, thus cannot be decarbonised directly.

## FIGURE/DATA





# Fifth-generation district heating and cooling: a framework for a holistic assessment

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## ABSTRACT

Fifth-generation district heating and cooling systems (5GDHC) are a key technology for the energy transition. However, due to their novelty, planning and design guidelines are scarce, hindering full-scale deployment. In our research, we focus on developing a framework for the assessment of 5GDHC systems based on energy efficiency, environmental, and economic performance criteria. We propose and model a 5GDHC for Australia, examining the opportunities and implementation challenges in a mild climate. The successful introduction of a 5GDHC system in Australia can create a path for the technology to be adopted in regions with no prior experience with district heating systems.

## INTRODUCTION

5GDHC systems are a key technology that can facilitate the energy transition through the integration of renewable energy sources and waste heat recovery. Their capacity to supply simultaneous heating and cooling via the same pipeline, as well as bidirectional energy flows, enable load balancing via demand synergy between different users. Moreover, heating and cooling electrification and coupling with the power grid enable the development of cross-sector synergies that would not be possible within each individual sector. Achieving net zero targets requires a fundamental change of the energy landscape and 5GDHC systems are uniquely positioned for the task. However, a holistic assessment of these systems is still needed. In our research, we propose a framework for an energy efficiency, environmental and economic assessment of 5GDHC and apply in the Australian context examining both the opportunities and implementation challenges.

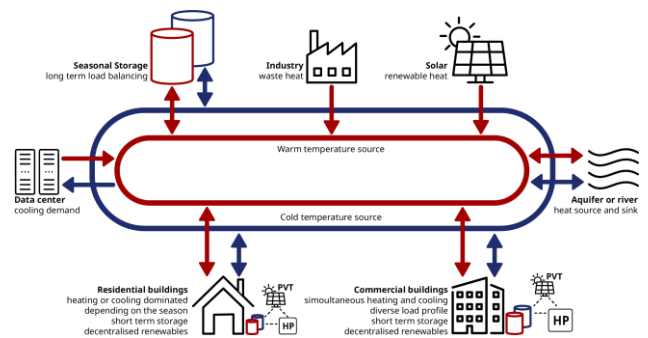
## DISCUSSION

The lack of planning and design guidelines means that existing 5GDHC systems are ad-hoc designs and the information publicly available is scarce. Similarly, most prior publications restore to ad-hoc and simplified modelling, assessing only specific aspect of such systems. Moreover, reliable data on embodied emissions and construction costs are difficult to find, particularly in regions without prior experience in district energy systems. Nevertheless, despite the challenges, preliminary research on Melbourne building archetypes, shows favourable within building and within network synergies which can lead to significant energy efficiency gains compared to business-as-usual solutions. The next step of the research will investigate whether these synergies translate in environmental and economic performance gains.

## METHODOLOGY

The aim of the research is to provide a framework for the energy performance, environmental and economic assessment of 5GDHC in the early stages of decision making where the performance of the system is compared to a business-as-usual solution. Among the several techniques available for the performance assessments, the most appropriate are deemed to be: system energy modelling, life cycle assessment, and levelized cost of energy. For the design of a 5GDHC system a technology database of energy generation, conversion and storage units is required. From the database, an algorithm selects the optimal size and configuration of the system with the goal of minimising the levelized cost of energy. Due to data availability, the scope of the LCA is limited to embodied and environmental GHG emissions, which are calculated from the model outputs. The framework will be validated through a case study in Melbourne.

## FIGURE/DATA





# The role of micro-hydro systems in urban setup with a focus on water-energy nexus

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## ABSTRACT

Climate change necessitates taking adaptation and mitigation measures in both water and energy sectors. Growth in the number of distributed clean energy resources emphasises the need for increase in the energy storage capacity (ESC). Highrises are good candidate for micro pumped-storage (MPS) installation at urban areas, storing surplus energy as water's gravitational potential energy. In this context, roof-mounted water tanks, either currently exists or planned to be designed, can be employed to contribute to load shifting and reliable operation of the grid. In this research, potential of the buildings for deploying as MPS is assessed from economic and environmental viewpoint. Investigation shows that the highrises located in Melbourne have a 50 MWh/day ESC at the community level.

## INTRODUCTION

The intermittent and non-dispatchable nature of renewable energies causes unexpected unbalances and bottlenecks on the grid. Battery banks as the most common energy storage method comes with environmental issues. Hence, MPS plants within city borders close to the energy consumption nodes will be a sustainable energy storage solution, provided that accurate and integrated analysis proves it economic feasibility and applicability. Combination of MPS with blue-roof structure also meet the stormwater management issue at the meantime, which is worth to be assessed under a unique scenario.

## METHODOLOGY

This study investigate the contribution of elevated water storage tanks to achieving net-zero emission target in Australia. The developed framework optimises MPS components in categorised buildings. Optimisation objectives are minimising total cost and peak-load emission, considering carbon credit. Energy arbitrage is the foundation of the economic assessment. EPANET 2 is applied for hydraulic and water quality simulation, and coupled with NSGA-II to optimise configuration of the MPS plants as a component of virtual power plant at the community level, as shown in Fig 1.

## DISCUSSION

According to 2021 wholesale electricity market data, published by AMEP, the lowest price bracket (under 25\$) and highest rates (above 125\$) had equal proportion at 7%. Associated with this energy arbitrage opportunity, levelised cost of storage and ESC for the MPS on a building with 150 m height and 1000 m<sup>2</sup> roof area are 0.127 Au \$/kwh and 47.5 kWh/day, respectively. The ESC of MPS reaches a considerable value of 50 MWh/day on community scale for the Melbourne case study. Buildings participating in this cumulative ESC tolerate standard distributed load of 3kN/m<sup>2</sup> on rooftop, and have the minimum 5kWh ESC. Analysis is carried out on the data published by the City of Melbourne (Fig 2 and 3).

## FIGURE/DATA

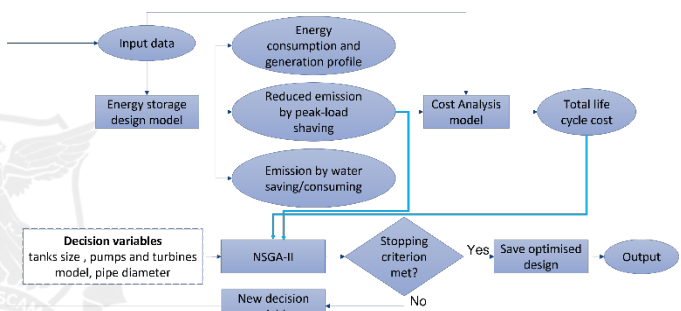


Fig 1. Research Methodology flowchart

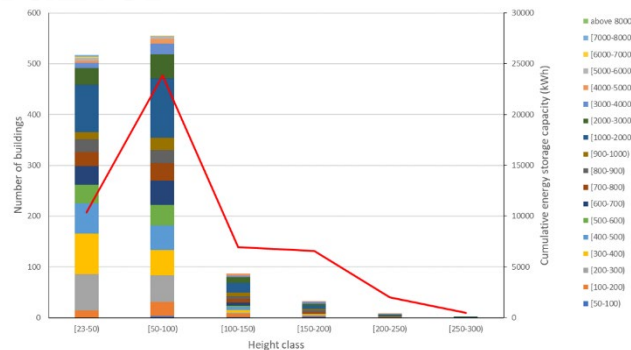


Fig 2. Buildings' classification and the cumulative ESC

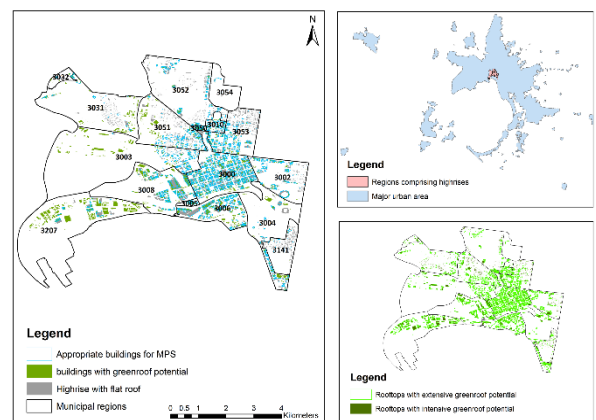


Fig 3. Geographical distribution of highrises for MPS installation







# Energy Allocation in Multi-owned Buildings: A Land Ownership Perspective

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## ABSTRACT

Adoption of Renewable Energy Systems (RES) in Multi-Owned Buildings is menial compared to detached homes. The multiple ownership of the RES in Common Properties (CP) develops energy and revenue allocation issues between the apartment owners in residential buildings. The research aims to develop a framework that establishes each apartment's share of the energy generated by the RES installed in CP. The study encompasses a stakeholder-inclusive approach considering the behavioural attributes in delineating energy allocation. The synergy between energy distribution and land administration from an ownership perspective will be investigated for better management of CP.

## INTRODUCTION

Rapid urbanisation encourages cities to create high-density 'Multi-Owned Buildings'(MOBs). The spatial limitation forces the apartment owners to install renewable energy systems (RES) in the multi-owned common properties (CP) managed by owners' corporations. The adoption of RES in CP develops issues related to ownership of energy and revenue associated with per-apartment CAPEX, OPEX and energy demand. The burgeoning prosumer-consumer-developer conundrum in MOBs necessitates a stakeholder-inclusive approach for efficient renewable energy allocation 'behind the meter'.

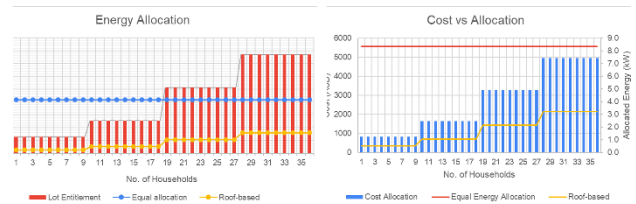
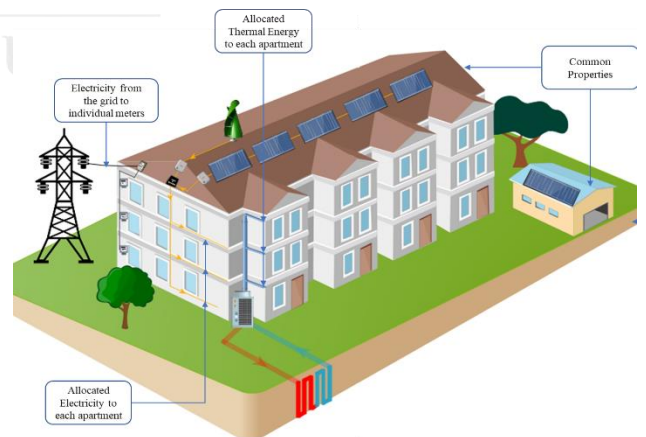
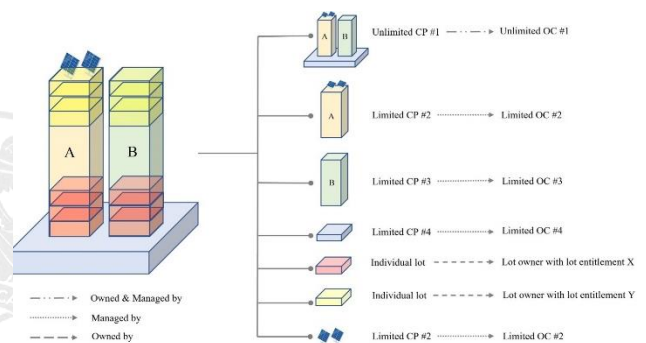
## METHODOLOGY

The research intends to introduce a novel concept of assigning the ownership of energy to apartment owners. Hence it is vital to identify the critical factors influencing the energy ownership and develop a definition for the same. Since the energy demand is dynamic, it is envisaged to include behaviour modelling of stakeholders through 'Agent-Based Modelling' to delineate the ownership of energy. The whole scenario is looked through the lens of land administration which demands the validation of common property ownership through digital twin, which will be attempted at a later stage of research.

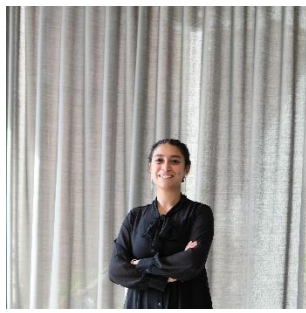
## DISCUSSION

The current research on energy allocation does not consider the ownership of the common properties in the allocation of energy. The discussed research focuses on delineating the ownership of the energy, irrespective of the type of Renewable Energy System (RES) intended, thus requiring only a single framework to promote the adoption of RES. The concept has policy implications, similar to the lot entitlement, that can aid surveyors in outlining the ownership of energy, facilitating the transition into net-zero emission buildings at a regional scale. The energy allocation concept, when implemented, can facilitate peer-to-peer energy trade among apartment owners.

## FIGURE/DATA



# Thermal comfort-based HVAC control strategy applying Koopman Universal Embeddings



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**Discipline:** Renewable Energy and Energy Efficiency

## ABSTRACT

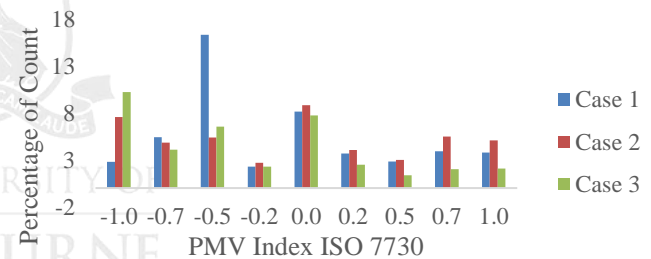
Heating, ventilation and air conditioning (HVAC) systems are essential for commercial buildings operation. They are primarily applied with the objective of maintaining an acceptable level of thermal comfort while limiting energy consumption. Due to several complex and interrelated phenomena, horizontal and vertical air temperature and velocity distributions are non-uniform in commercial spaces, causing thermal dissatisfaction, possible contaminant storage and recirculation and energy waste. Numerous researchers have investigated thermal comfort based control strategies, and yet accurate representation and application of control models were not properly applied. The overarching aim of the proposed research is to improve the occupants' thermal comfort for the indoor environment.

## INTRODUCTION

With the worldwide prolonged lockdowns brought on by COVID 19, the control and monitoring to pursue the highest level of indoor thermal comfort are becoming essential. The objective is to promote suitable living and working circumstances for indoor space occupants while balancing comfort with energy usage. Thermal comfort is attained when the body of the occupant finds equilibrium with the surrounding conditions of indoor air variables. However, traditional control systems solely use temperature readings from thermometers as an indication of indoor thermal comfort. In connection with that, a number of indices have been created to assess thermal comfort levels. The most widely used thermal comfort metric that takes into consideration both air parameters and occupants' physiological circumstances is called Predicted Mean Vote (PMV).

## DISCUSSION

The PMV-CFD representation of thermal comfort enabled effectively describing the cold-spots and could quantify the thermal comfort perception based on a set of scenarios. Compared to the APDI approach, this model can quantify the human perception against variations of the airflow.

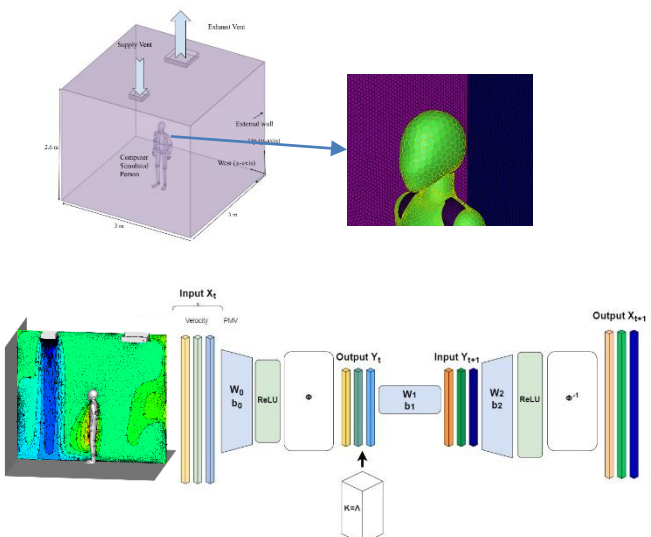


Using the output of this model provided a breadth of data presenting high dimensional state spaces in transient time steps and enabled global dimensionality reduction.

## METHODOLOGY

In this research, a co-simulation is created between Computational Fluid Dynamics (CFD), representing the indoor thermal transient conditions, and Koopman operator system identification as the basis of linear quadratic regulatory feedback control strategy. Cold air distribution system's performance is evaluated using PMV thermal comfort index embedded into a CFD model. Scenarios of variable indoor conditions are considered to demonstrate the benefits and limitations of the proposed CFD-PMV approach, where a  $k-\epsilon$  turbulence model for indoor airflow is considered. Koopman operator system identification is essential to linearise the nonlinear behaviour of thermal comfort to be utilised as the basis for optimal sensor placement application and simple linear feedback control model. The system identification is mapped using deep autoencoder network combined with an auxiliary Koopman, where Pytorch encoder, decoder, weights, biases and optimization are defined.

## FIGURE/DATA

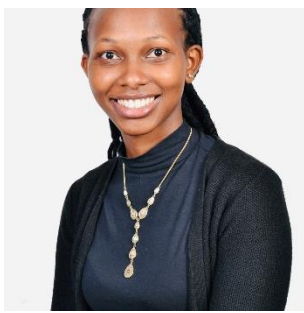




THE UNIVERSITY OF  
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# ENGINEERING MANAGEMENT





# How are decarbonisation decisions evaluated to achieve carbon neutrality in building projects?

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## ABSTRACT

Decarbonisation decisions entail trade-offs and synergies between various competing variables. Based on a systematic literature review in combination with empirical evidence from interview with experts, this research effort identified whole lifecycle cost, whole lifecycle energy use, exergetic lifecycle and whole lifecycle emissions as the four critical variables for evaluating decarbonisation decisions. Each of these critical variables was then assigned to different evaluation criteria and mapped onto the respective project lifecycle stages. A total of 33 evaluation criteria were identified for the four decision variables. These findings will assist building professionals to evaluate optimal decarbonisation alternatives across the entire project lifecycle.

## INTRODUCTION

Ambitious sustainability aspirations such as the Paris Agreement targets and the Sustainable Development Goals (SDGs) require rapid, timely and sufficient plans for emission reduction in the built environment (Moallemi et al., 2021). One of the optimal strategies to realize sustainable structures is to select decarbonisation alternatives that will present a holistic view of environmental impacts (Röck et al., 2020). This research effort aims to examine how decarbonisation alternatives can be evaluated along the project lifecycle to achieve carbon neutrality in building projects.

## METHODOLOGY

- Findings from a systematic literature review were supplemented with interviews with 15 purposively-sampled experts.
- The audio-recorded interviews were transcribed and the terms used by the interviewees to refer to the key decision variables identified. Four key decision variables emerged from analysis (Fig.1).
- A cluster of evaluation criteria for each of the key variables was identified from the literature review in line with the core indicators provided by ISO 21929 (Fig.2).

## DISCUSSION

- No universal definition of carbon neutrality.
- One of the main causes of complexity in decision making is the various performance objectives that need to be considered (Salvadó et al., 2022).
- Different metrics are used to assess carbon neutral targets and performance.
- Majority of the studies focus on energy consumption and emissions as the main decision criteria.
- This research effort bridges this gap by unpacking all the decision variables related to a building's environmental performance (Fig.1) together with their respective evaluation criteria (Fig.2).

## FIGURE/DATA

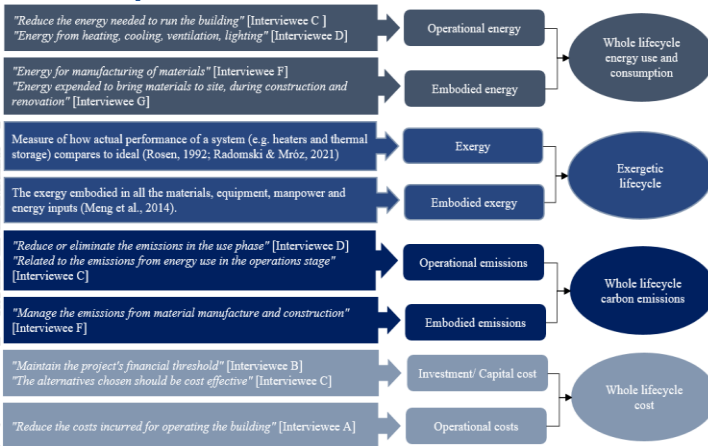


Fig.1: Key decision variables (Too et al., 2022)

Table 1: Key evaluation criteria (Too et al., 2022)

	Energy	Emissions	Economy	Exergy
Initiation	Maximise energy saving potential, economic benefit, minimise GHG emissions and exergy losses.			
Planning	Energy efficiency, Building envelope design, GBR, Renewable energy tech	Fuel consumed, circularity, materials, carbon sequestration, carbon credits.	Investment cost, Investment appraisal.	Quality & quantity of energy & materials.
Delivery	Construction technologies, fuel consumed, material footprint, waste management, investment appraisal (e.g. ROI, NPV, Payback period) and exergy losses.			
Closure	Construction technologies, fuel consumed, material footprint, waste management, investment appraisal (e.g. ROI, NPV, Payback period) and exergy losses.			
Operations	Energy efficiency, energy consumption, renewable energy	Annual OE&EE, carbon credits	Annual savings, maintenance cost, energy cost	Exergy consumption, heat demand

