Hong Kong 2022 International Urban Forestry Conference

Well-being: Our Urban Forest · Our Community

發展局
Development Bureau

Engineering a safer urban forest under extreme storms

建設可抵禦極端風暴的安全城市森林

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香港 研究資助局

Title: *Engineering a safer urban forest under extreme storms*

Project coordinator: Prof. Anthony Leung (ceanthony@ust.hk)

Coordinating institution: **HKUST**

Participating institutions: **HKU**; **CityU**

Start date: 30 June 2021

End date: 29 June 2024 (**three years**)

Total RGC funding: HK$ 6,263,998 (excluding overheads)

To create a safer, greener and more sustainable urban forest

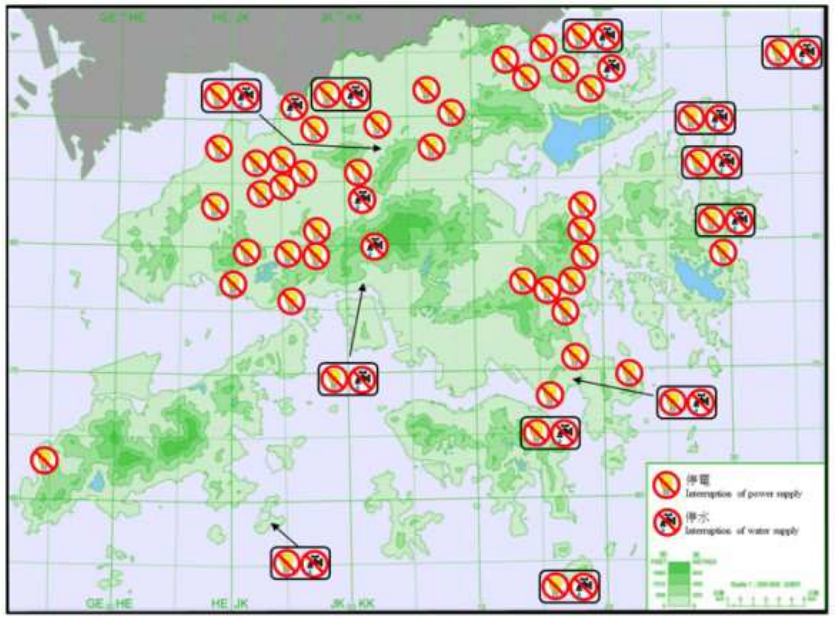
The ferocious strike of Super Typhoon *Mangkhut* on 16 Sep 2018

No. 10 Typhoon signal **for 10 hours**;

Sustained max. wind speed at 250 km/h

[1]**Most powerful** since records began in 1946;

- > 60 000 reports of fallen trees
- **Direct economic loss: HK$ 4.6 billion**
- Storage area of 9k-ton tree waste = 12 football pitch



Reports of interruption of power and water supply

([1]https://www.hko.gov.hk/en/cwsrc/index_mangkhut.html, https://www.hko.gov.hk/en/informtc/mangkhut18/report.htm, https://www.hko.gov.hk/en/research_forum/files/RF2019_CLP.pdf)

Tree risk is a global problem

***Jebi* (2018);** Most powerful storm in 25 years

Source: alamy.com

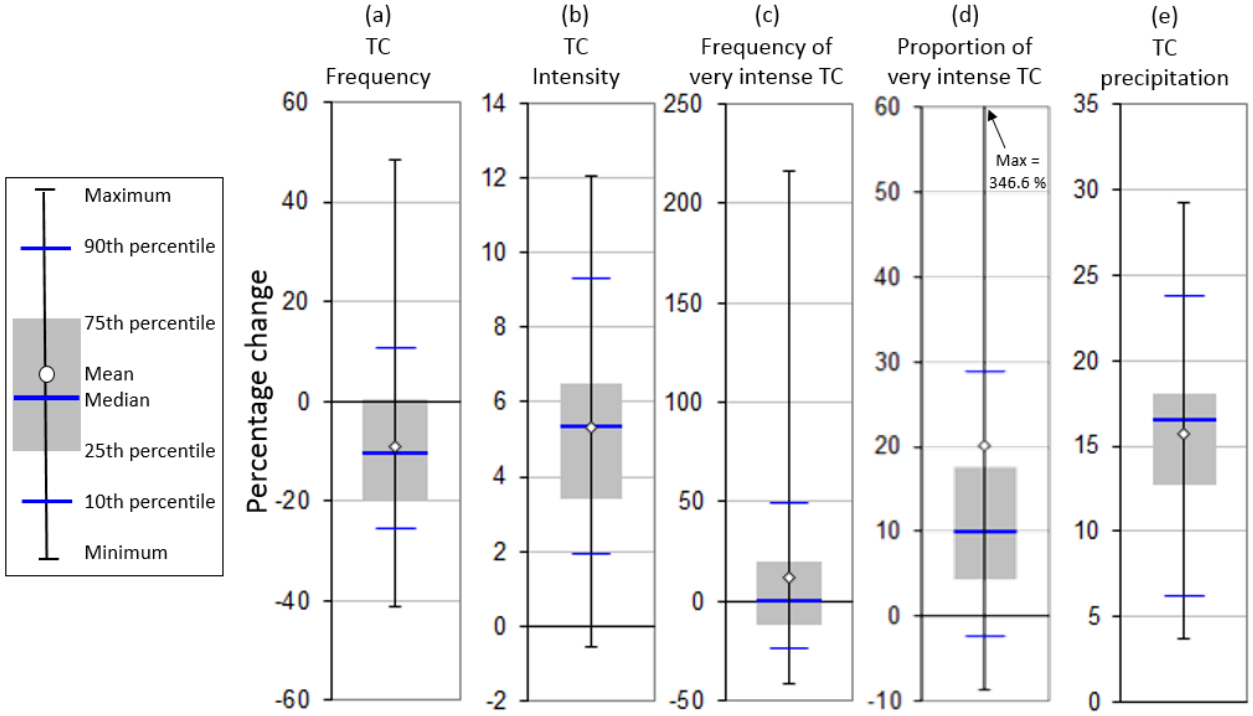
***Florence* (2018);** Category IV major hurricane

Source: thetrucker.com

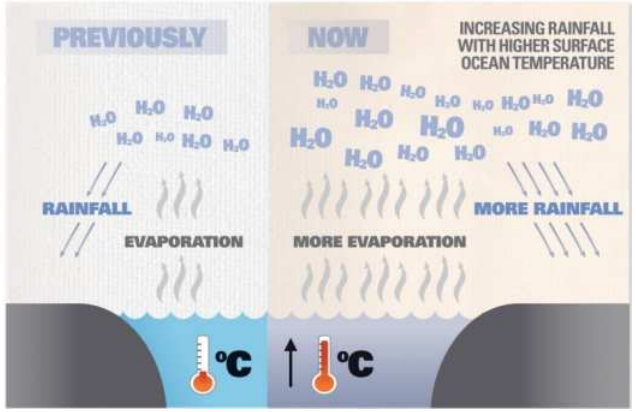
Source: thenationalnews.com

***Amphan* (2020);** Max. wind speed = 260 km/h

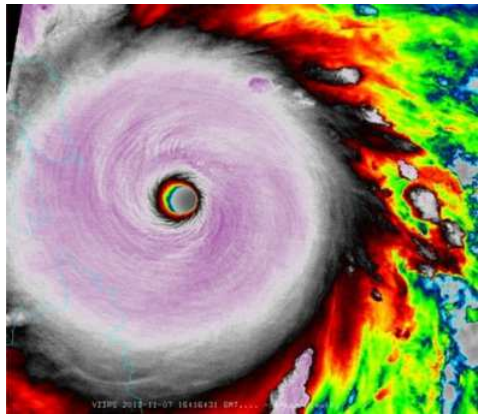
Climate change will fuel the future storms



Summary distributions of projected changes
for the western North Pacific based on the 2°C warming.



(Source: Climate Commission)



(Source: Dan Lindsey, NOAA)

Reduce in **tropical cyclone (TC) frequency**, but Increase in **TC intensity**, TC related rainfall rates and proportion of **very intense TCs** in a **warming climate**

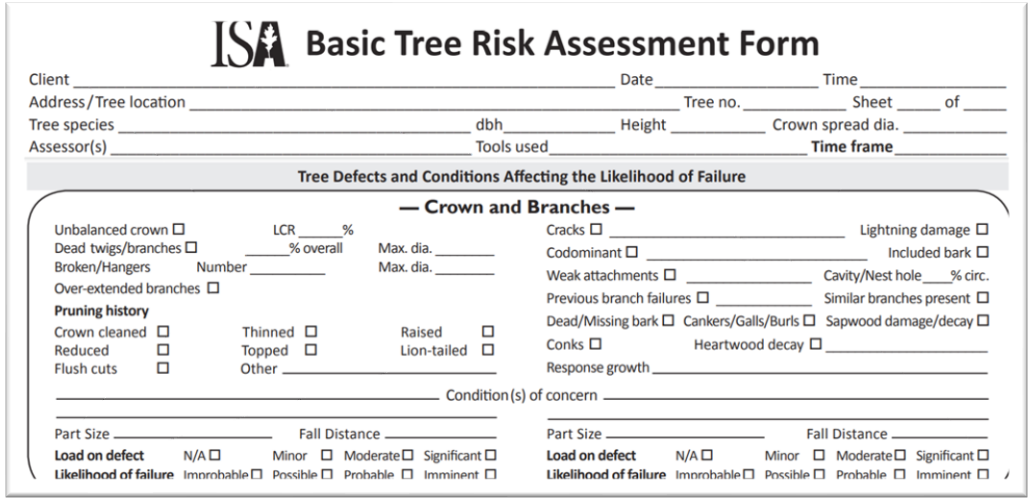
(Cha, E J, T. R. Knutson, T.C. Lee, M. Ying, T. Nakaegawa, 2020 : Third Assessment on Impacts of Climate Change on Tropical Cyclones in the Typhoon Committee Region – Part II: Future Projections, Tropical Cyclone Research and Review, https://doi.org/10.1016/j.tcrr.2020.04.005)

Major problem 1: Poor urban soil quality

Current approaches and limitations:

- *Heavily compacted fill soil in tree pits*
  - Discourage root growth and anchorage *(Bengough and Mullins 1990)*
- *Structural soil* *(Jim 1998)*
  - Gap-graded gravel and mineral soil
  - Lack of available water and nutrient due to limited volume of mineral soil
  - Amendment by hydrogel, yet unstable – long-term efficiency

Major problem 2: Tree risk assessment method



ISA Basic Tree Risk Assessment Form

Client _____ Date _____ Time _____
Address/Tree location _____ Tree no. _____ Sheet ____ of ____
Tree species _____ dbh _____ Height _____ Crown spread dia. _____
Assessor(s) _____ Tools used _____ Time frame _____

Tree Defects and Conditions Affecting the Likelihood of Failure

— Crown and Branches —

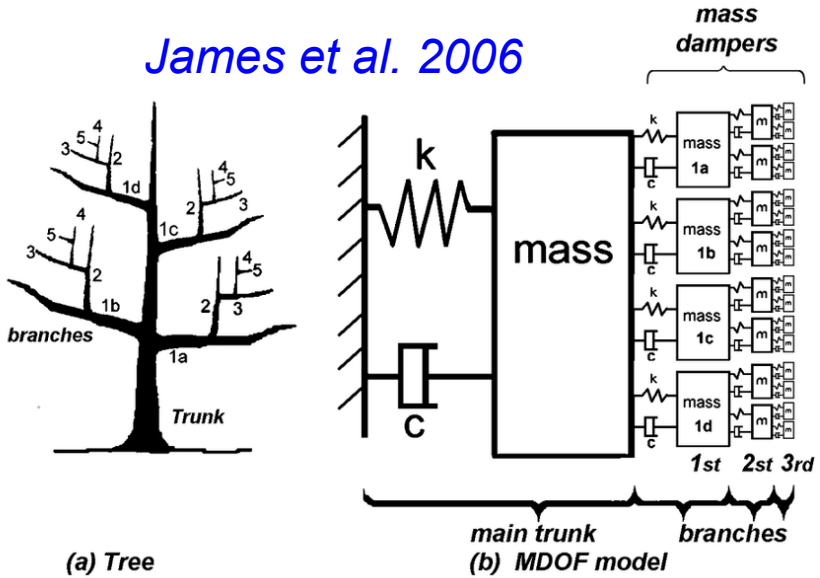
Unbalanced crown ☐ LCR ____% Cracks ☐ _____ Lightning damage ☐
Dead twigs/branches ☐ ____% overall Max. dia. _____ Codominant ☐ _____ Included bark ☐
Broken/Hangers Number _____ Max. dia. _____ Weak attachments ☐ _____ Cavity/Nest hole ___% circ.
Over-extended branches ☐ Previous branch failures ☐ _____ Similar branches present ☐
Pruning history Dead/Missing bark ☐ Cankers/Galls/Burls ☐ Sapwood damage/decay ☐
Crown cleaned ☐ Thinned ☐ Raised ☐ Conks ☐ Heartwood decay ☐ _____
Reduced ☐ Topped ☐ Lion-tailed ☐ Response growth _____
Flush cuts ☐ Other _____

Condition(s) of concern _____

Part Size _____ Fall Distance _____ Part Size _____ Fall Distance _____
Load on defect N/A ☐ Minor ☐ Moderate ☐ Significant ☐ Load on defect N/A ☐ Minor ☐ Moderate ☐ Significant ☐
Likelihood of failure Improbable ☐ Possible ☐ Probable ☐ Imminent ☐ Likelihood of failure Improbable ☐ Possible ☐ Probable ☐ Imminent ☐

Current approaches and limitations:

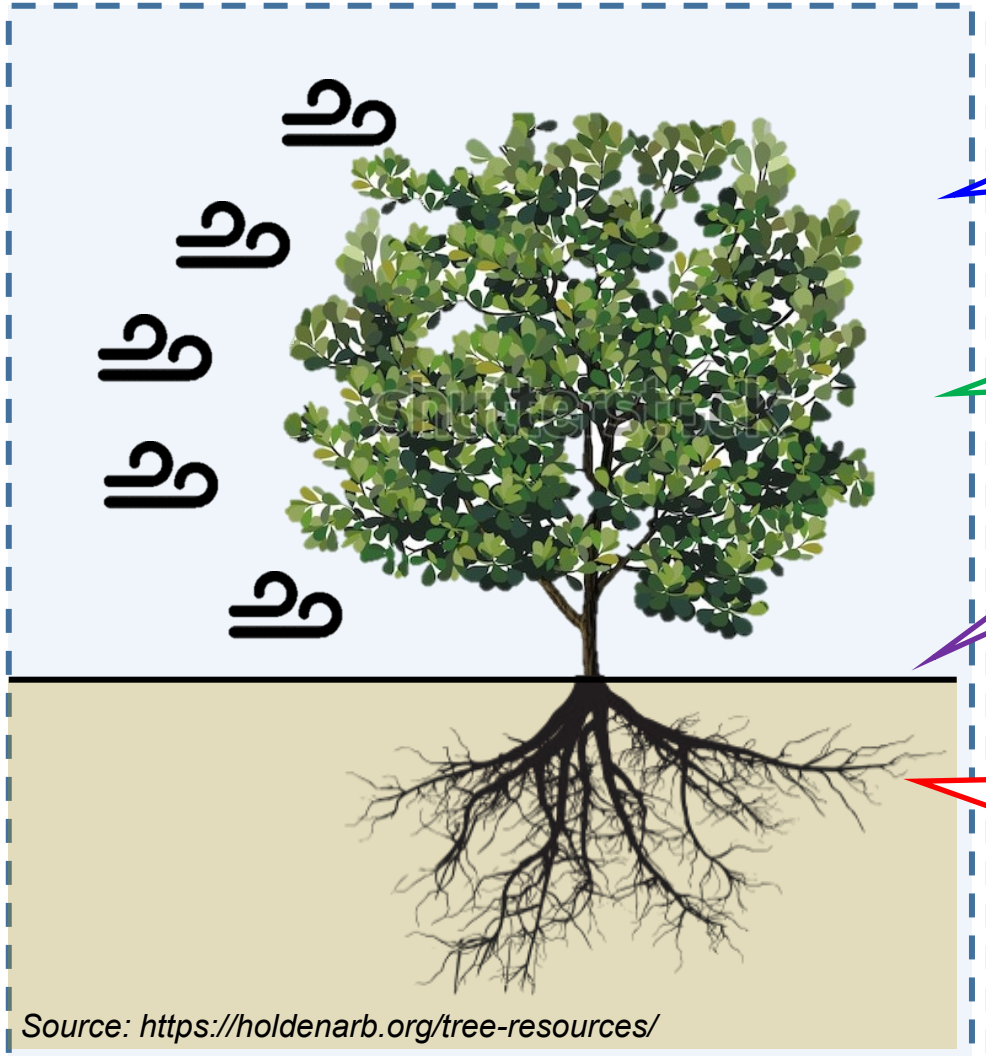
- *Visual assessment of tree "health"*
  - Arboricultural research approach
  - Based on tree physiology and healthiness
  - Qualitative, empirical and subjective



- *Existing theoretical approaches:* ***tree dynamic models*** *(James et al. 2006)*
  - Ignoring **interaction with wind**
  - Ignoring **soil-root interaction**
  - Ignoring **uncertainties and variabilities**

Demanding multi-disciplinary research approach

Problem



Source: https://holdenarb.org/tree-resources/

A nonlinear 'live' structure

Scientific issues

- **Wind-structure (tree) interaction**
- **Tree ecology and biophysics**
- **Soil science**
- **Soil-structure (root) interaction**
- **Variabilities**

New opportunities

Tree stability
can be assessed by

Engineering methods
+
Cross-disciplinary research

Novel approaches

Multi-disciplinary project team

- Core project team (**HKUST** / **HKU** / **CityU**)

Anthony Leung
Geotechnical engineer

Tim Tse
Structural/wind engineer

Sergio Lourenco
Soil scientist

Billy Hau
Ecologist

Yu Wang
Risk engineer

- Local collaborators

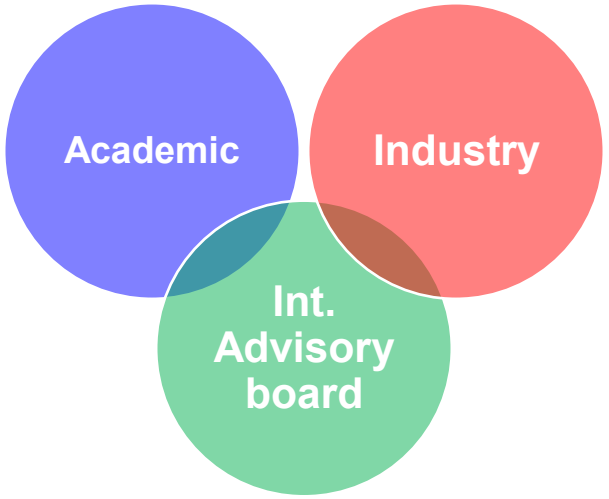
Jon Picker
Experienced Arborist

TC Lee
Senior Scientific Officer/HKO

- International collaborators

Dr Alexia Stokes (left): world-renowned plant biophysicist in tree biomechanics and tree root anchorage under wind

Dr Barry Gardiner (right): leader in European forest tree research and management



Task A: New urban soil: hydrochar-amended soil

- **Key objectives:** to test the properties of **hydrochar-amended structural soil (HASS)** to facilitate **root anchorage**, while not compromising road design requirement

Upcycling tree waste and yard waste to **new resources**

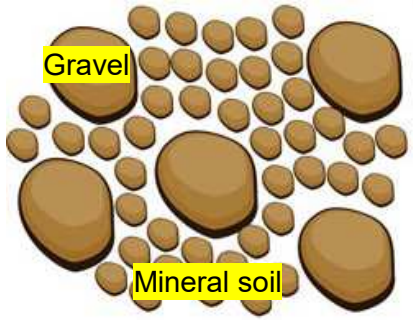
Environmentally-friendly, sustainable!

Pyrolysis

Hydrochar

Amend

Structural soil



Testing

Micro

Macro

Outputs

Physiochemical properties

Favourable to root growth and root water uptake?

Geotechnical properties

Bearing capacity, stiffness, support urban road design?

Task B: In-situ tree characterisation & testing

- **Key objectives:** (i) field mapping of tree characteristics; (ii) *in-situ* tree tests; and (iii) tree biomechanical tests under complex loading conditions

15 *Ilex rotunda* have been transplanted in HKUST campus

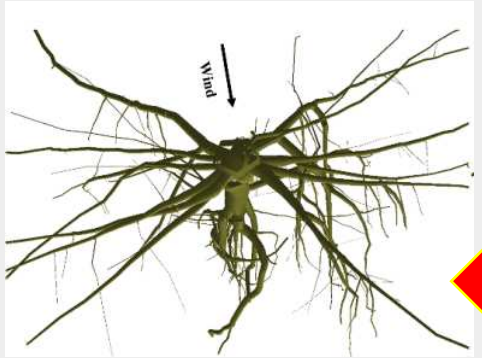
Newly-designed laboratory setup for tree biomechanical tests

Outputs

Cyclic tree mechanical properties

Effects of **new urban soil** (**Task A**) on tree anchorage behaviour

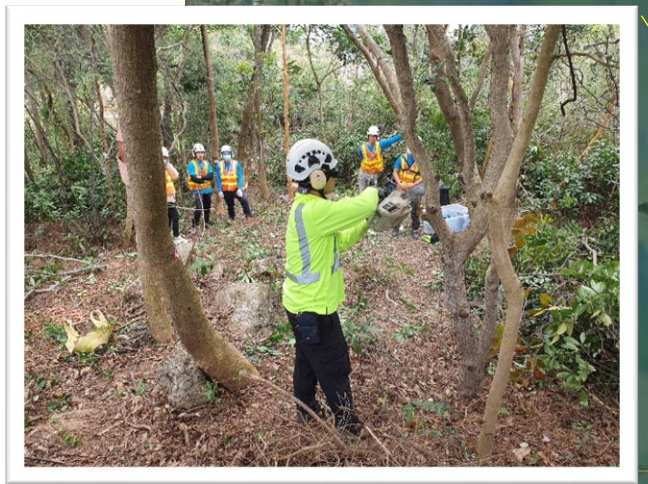
3-D coordinates of tree branch and root architecture



Laser scanning

Task B: In-situ tree characterisation & testing

Destructive quasi-static pull-over tests



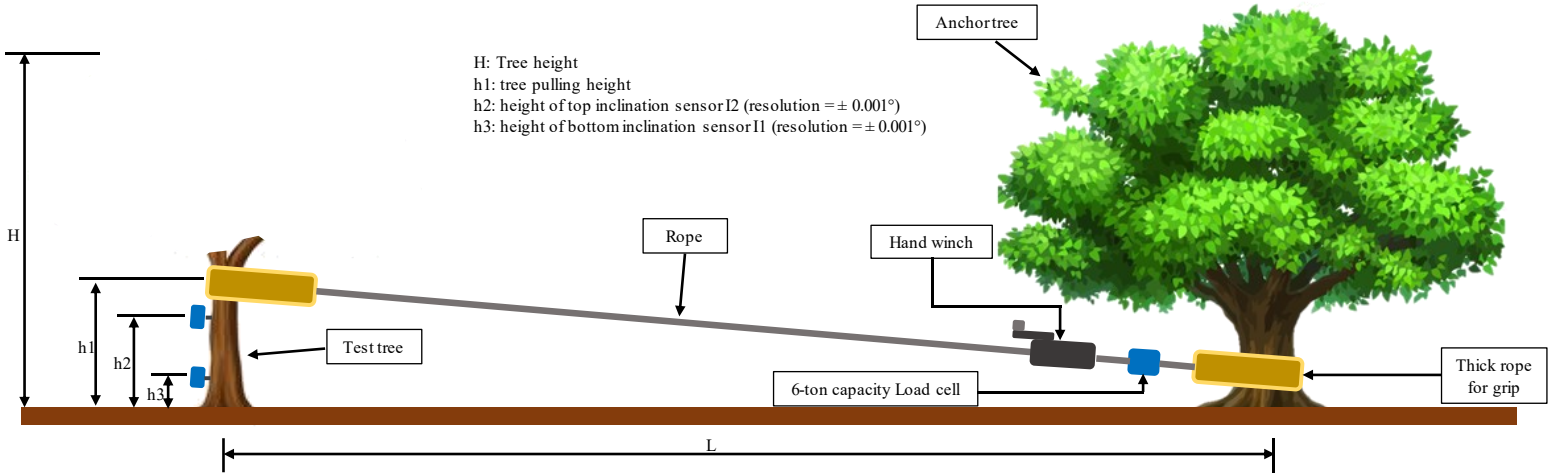
HKUST Campus

Jon Picker
ATP Ltd.

Non-destructive cyclic tests

***Acacia confuse* 臺灣相思樹**

Task B: In-situ tree characterisation & testing

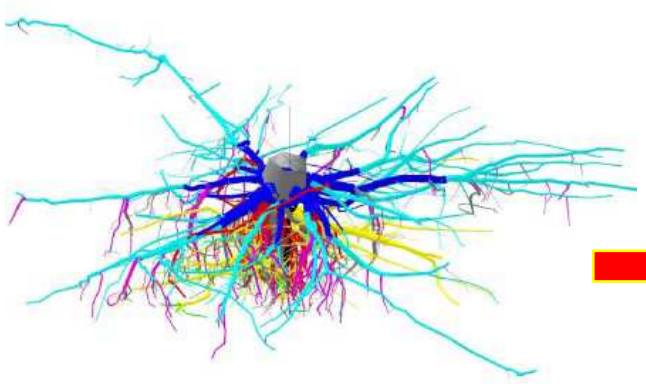


Task C: Modelling soil-root interaction

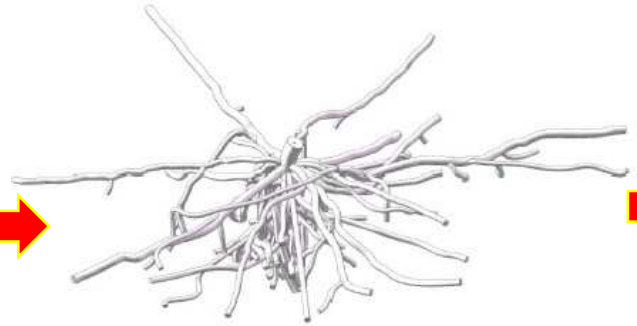
Collaboration with Prof. J. A. Knappett from **Dundee Uni., UK**

Modelling plant roots realistically by 3-D printing

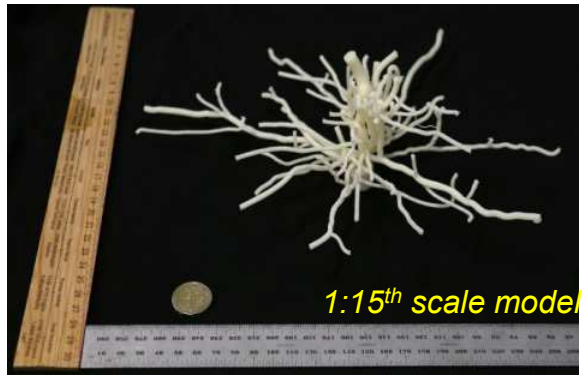
Modelling



19 years-old ***P. Pinaster***
(Danjon & Reubens 2008)



Idealising the root model for manufacturing



3-D printed root model using ABS plastic

Testing

Burying root models in soil

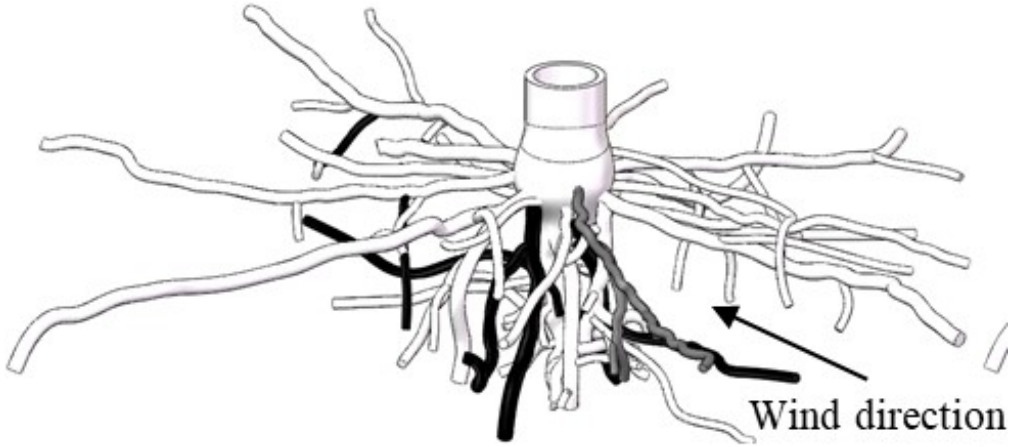
Centrifuge modelling

Controlled push-over tests

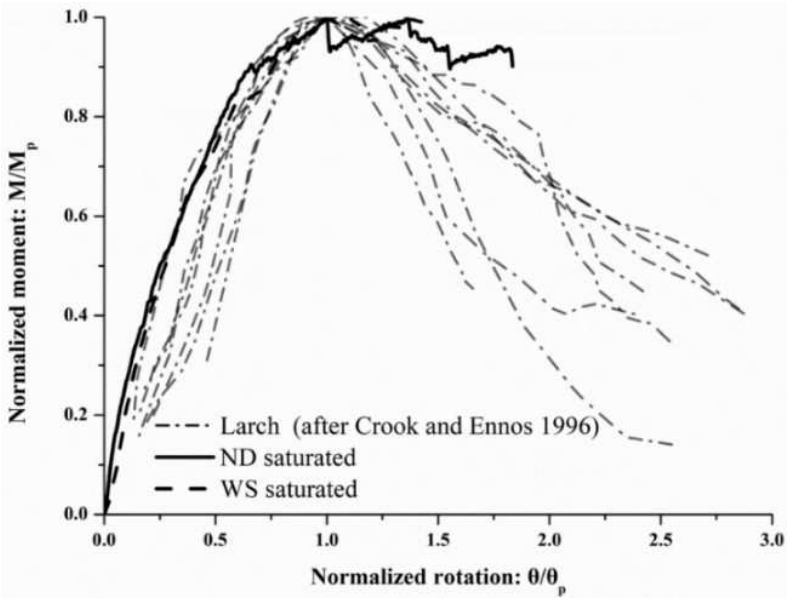
Task C: Modelling soil-root interaction

In-depth interpretation of root anchorage mechanisms

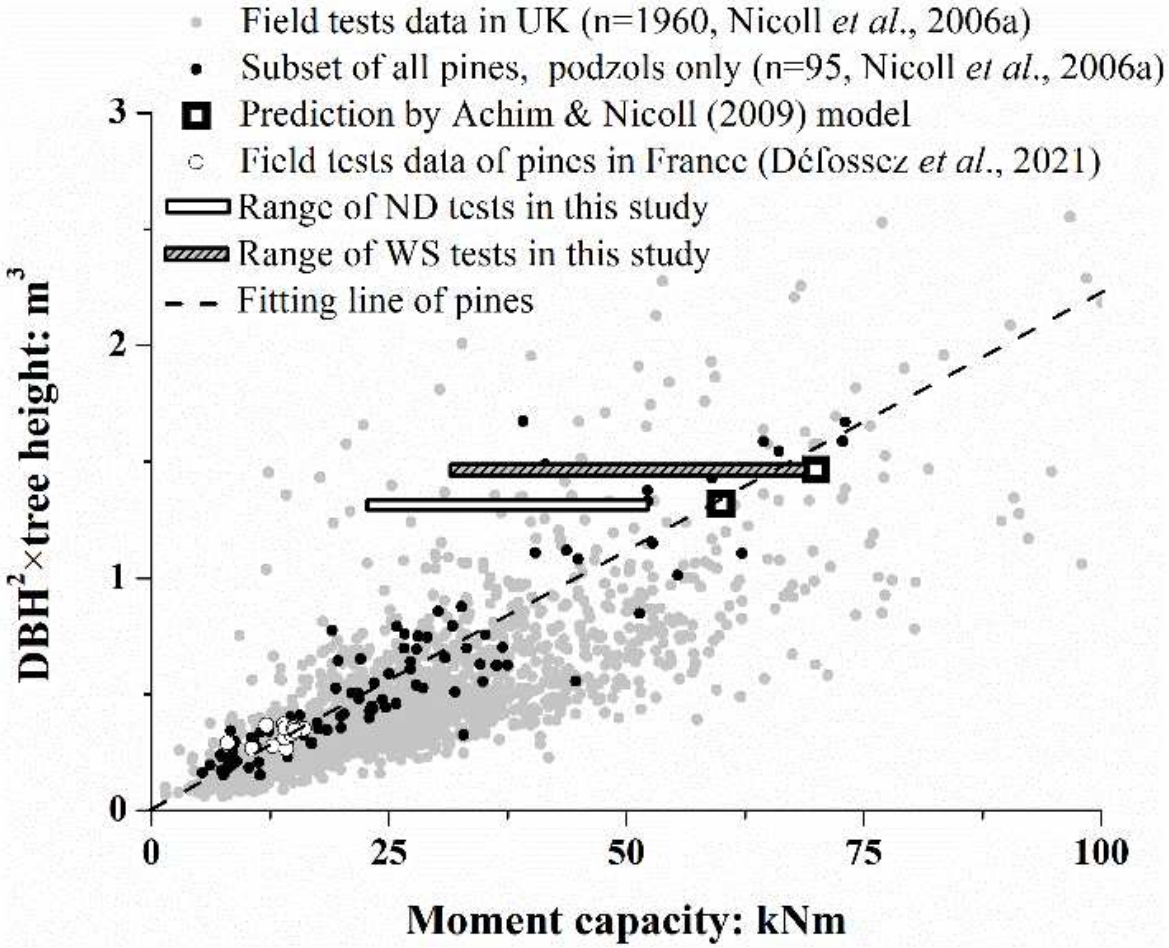
Collaboration with Prof. J. A. Knappett from **Dundee Uni., UK**



Examination of **root failure mode**



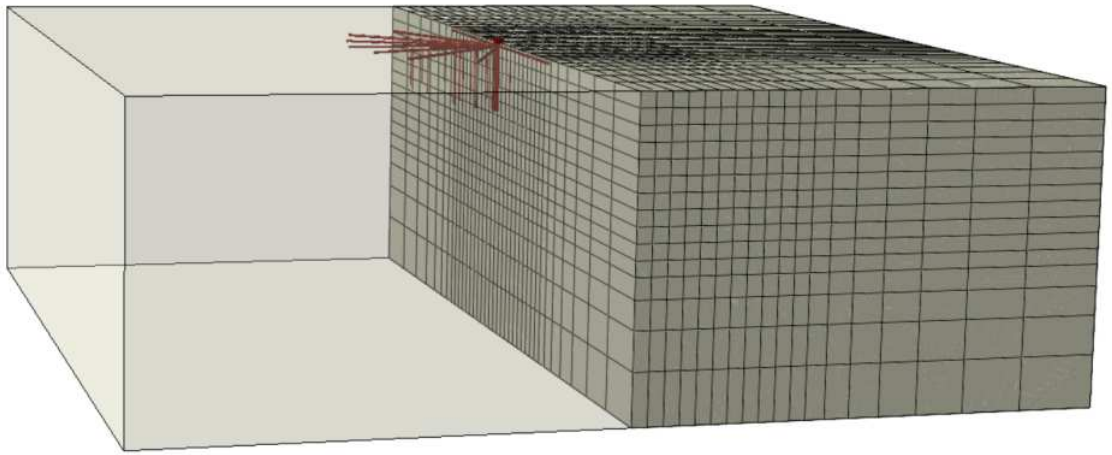
Moment-rotation curve

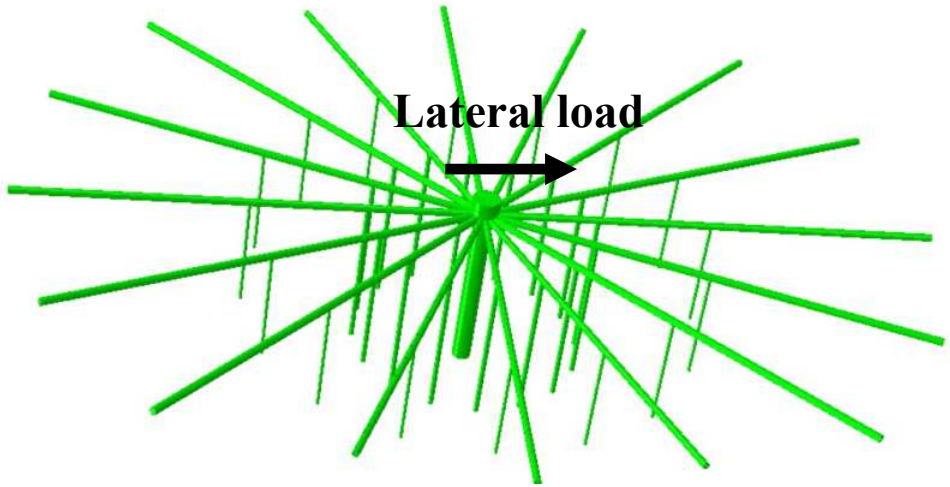


Comparison of **field measurements**

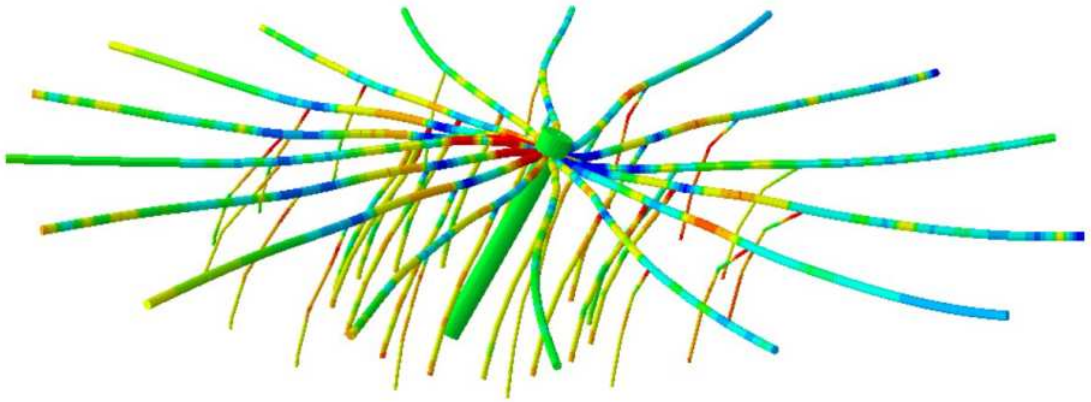
Task C: Modelling soil-root interaction

3-D computer modelling and analysis of root anchorage





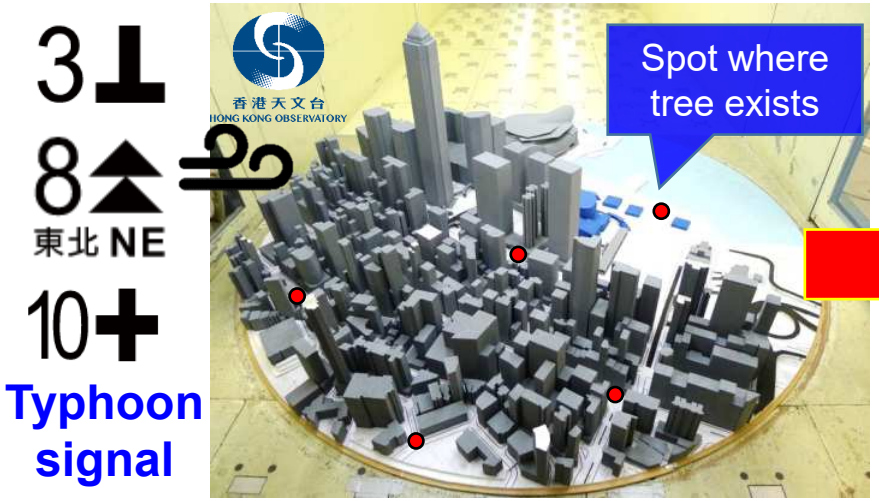
- Model **calibration** and **validation** against physical and field tests.
- Model **prediction** for advancing the understanding of soil-root interaction and root failure mode



Task D: Modelling wind-tree interaction

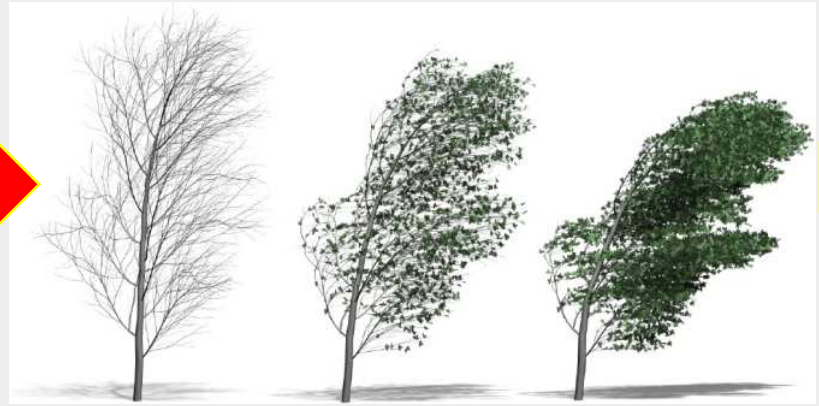
- **Key objectives:** to carry out novel multi-scale wind tunnel modelling to investigate wind-tree-**soil** interaction and stress distribution in deformed trees

City-scale

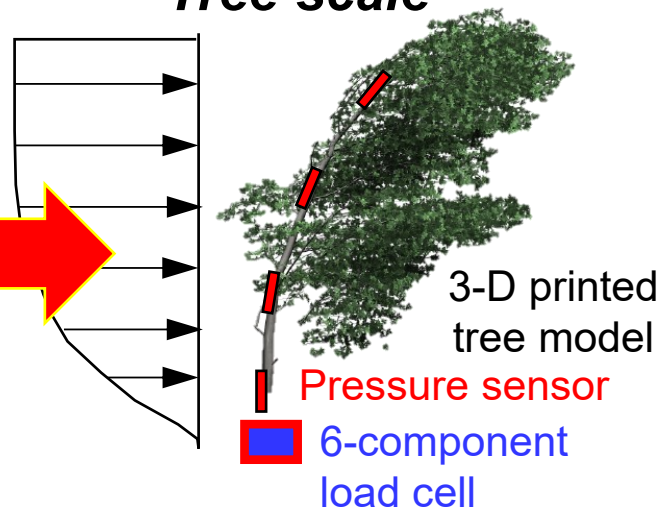


Tree survey results from Task B

Snapshot of tree deformation under wind



Tree-scale



Outputs

Effects of soil and roots on tree drag behaviour

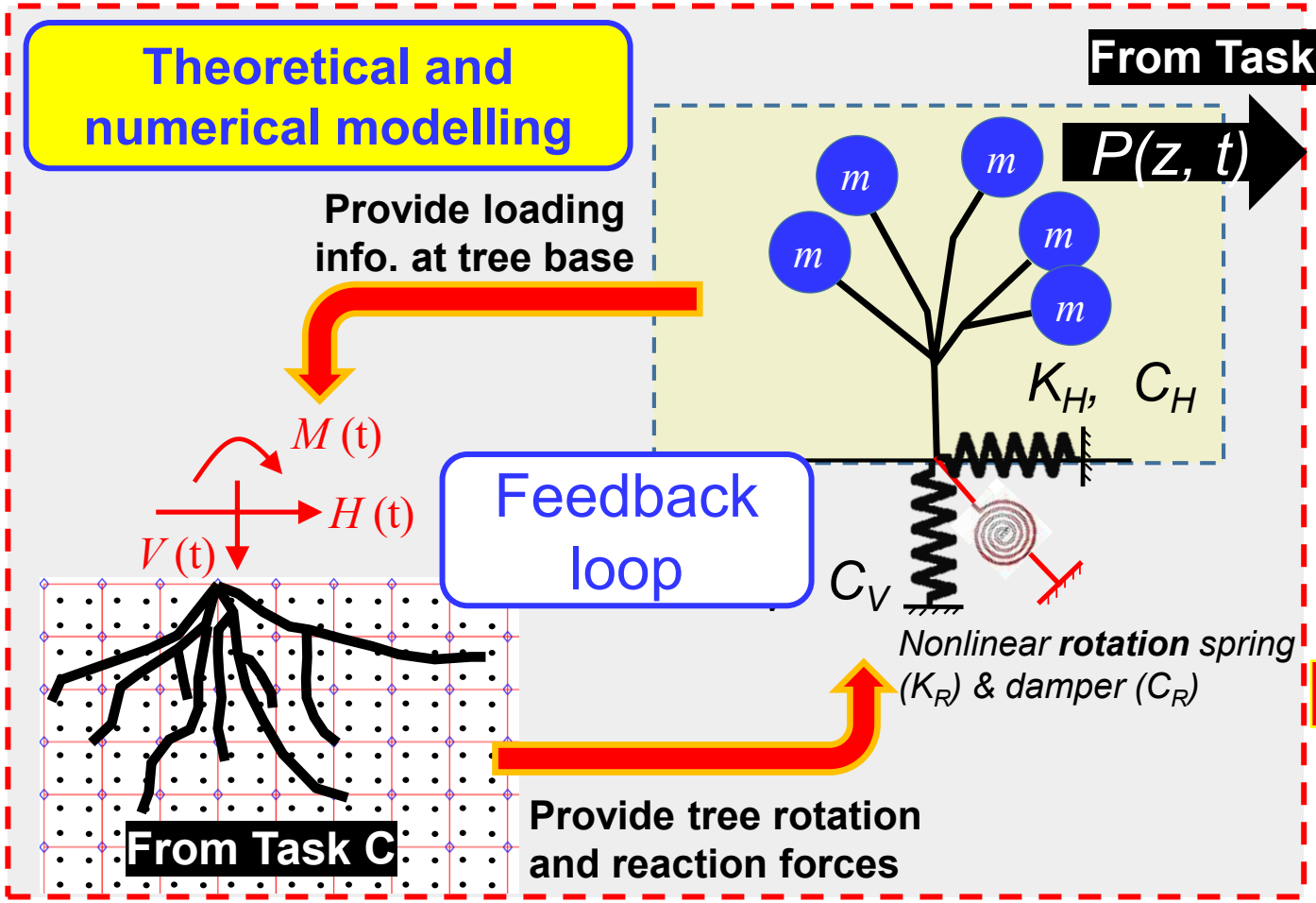
Amplitude-dependent wind-loading time functions

$$P(z,t) = \frac{1}{2}\rho U^2 D[C_L(z,t) + C_M(z,t)]$$

Developed by Co-PI (Tse); *Chen et al. (2017)*

Task E: Reliability-based wind-tree-soil (WTSI) interaction models

- **Key objectives:** to **integrate** the new knowledge from **Tasks A – D** in order to develop new reliability-based WTSI models for use in predicting tree stability



Integrating material variabilities

Soil properties	**From Task A**
Tree properties	**From Tasks B and C**
Wind charac.	**From Task D**

Quantitative and **objective** assessment of **tree stability** and **tree tilting**

Verified by the field tests in Task B

Thank you very much for listening