Computational Modelling in Postharvest Technologies

Corné Coetzee
Department of Mechanical & Mechatronic Engineering

Tarl Berry
Department of Horticultural Sciences
Citrus Research International

Photo by Stefan Els

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- Examples
  1. Bulk materials handling
  2. Packaging design
  3. Cold chain management

Computational Methods

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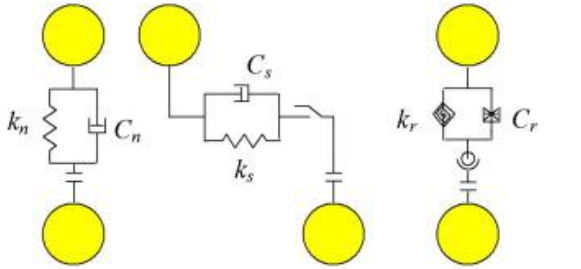
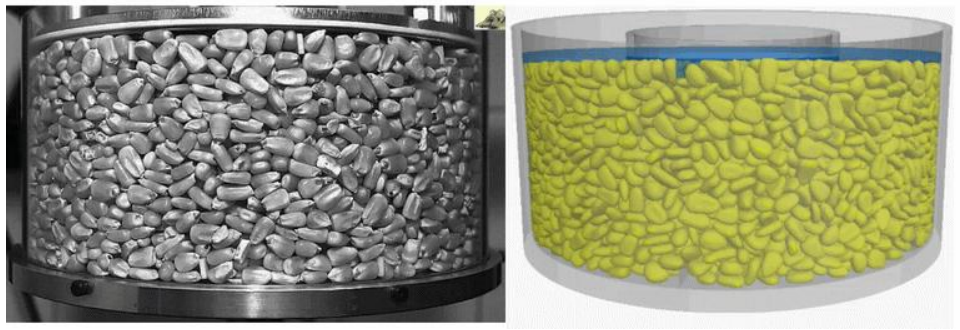
- Finite Element Method (FEM)
  - Structural analysis of packaging
- Computational Fluid Dynamics (CFD)
  - Modelling of fluid flow and heat transfer in cold chain

Discrete Element Method (DEM)

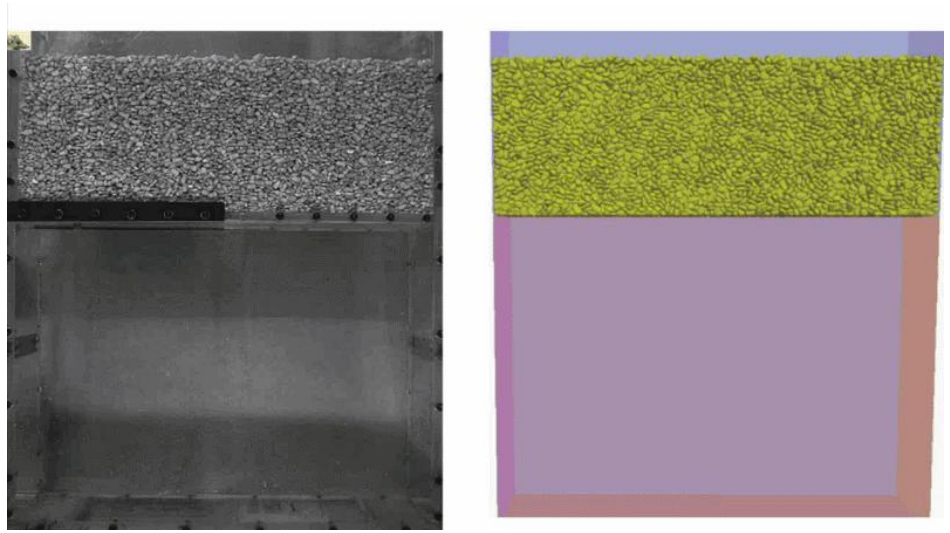
Bulk Materials Handling using DEM

- Calibration of input parameters





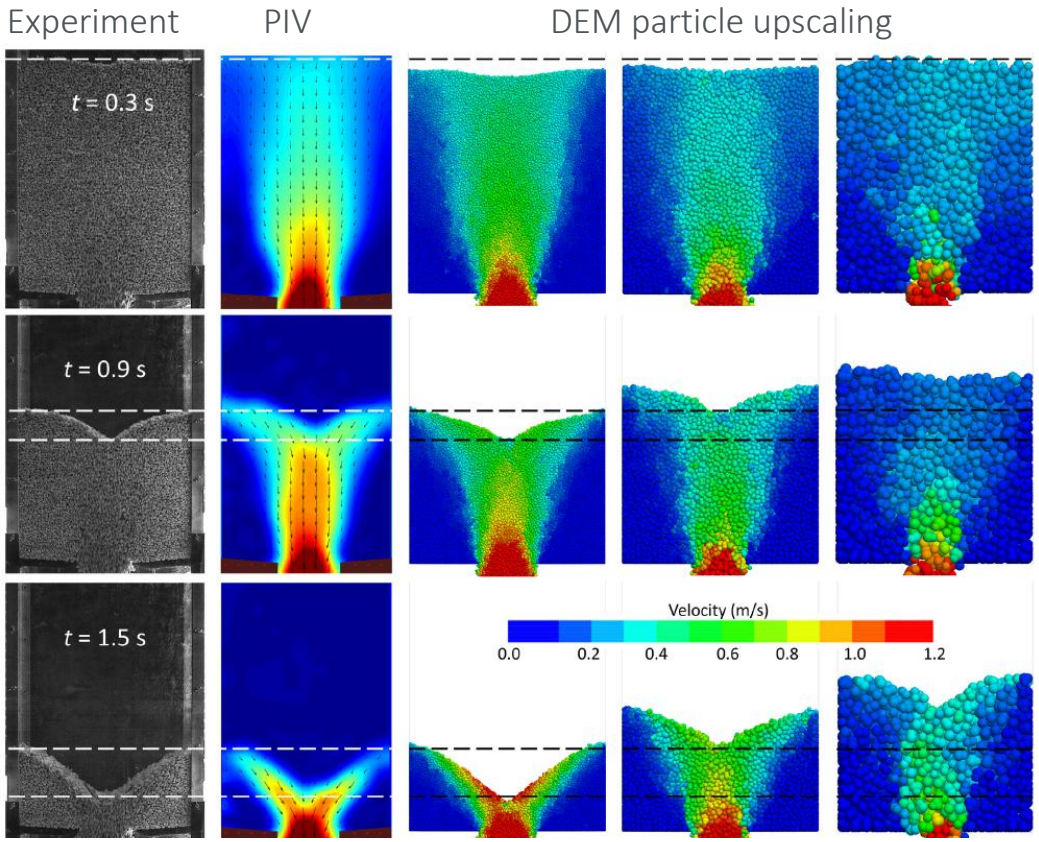
Ring shear test (corn grains)

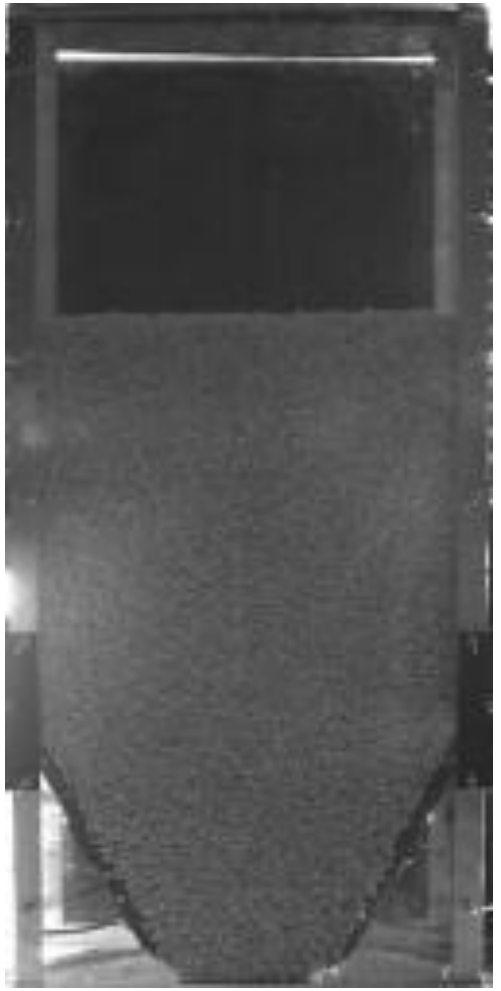


Draw down flow test (corn grains)

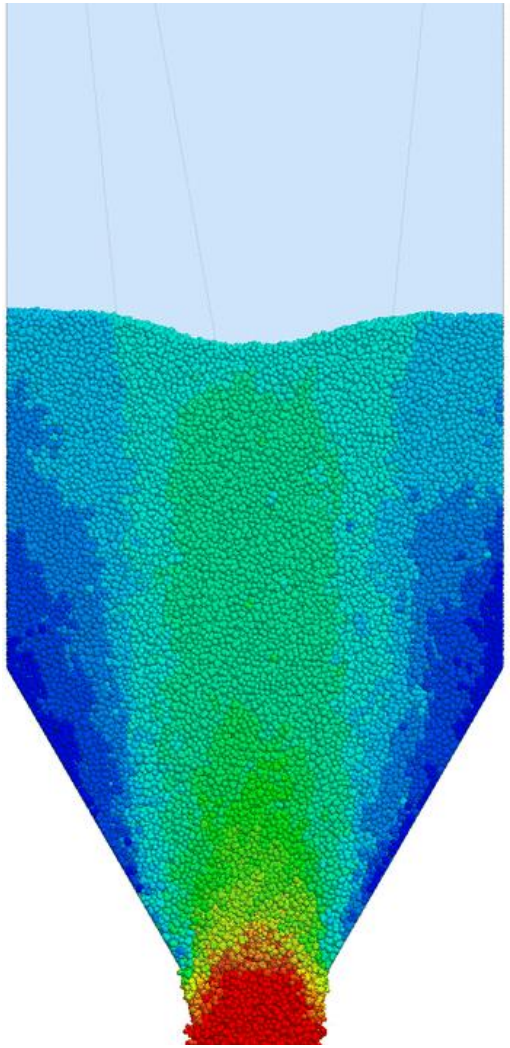
Bulk Materials Handling using DEM

- Hopper, bin and silo discharge



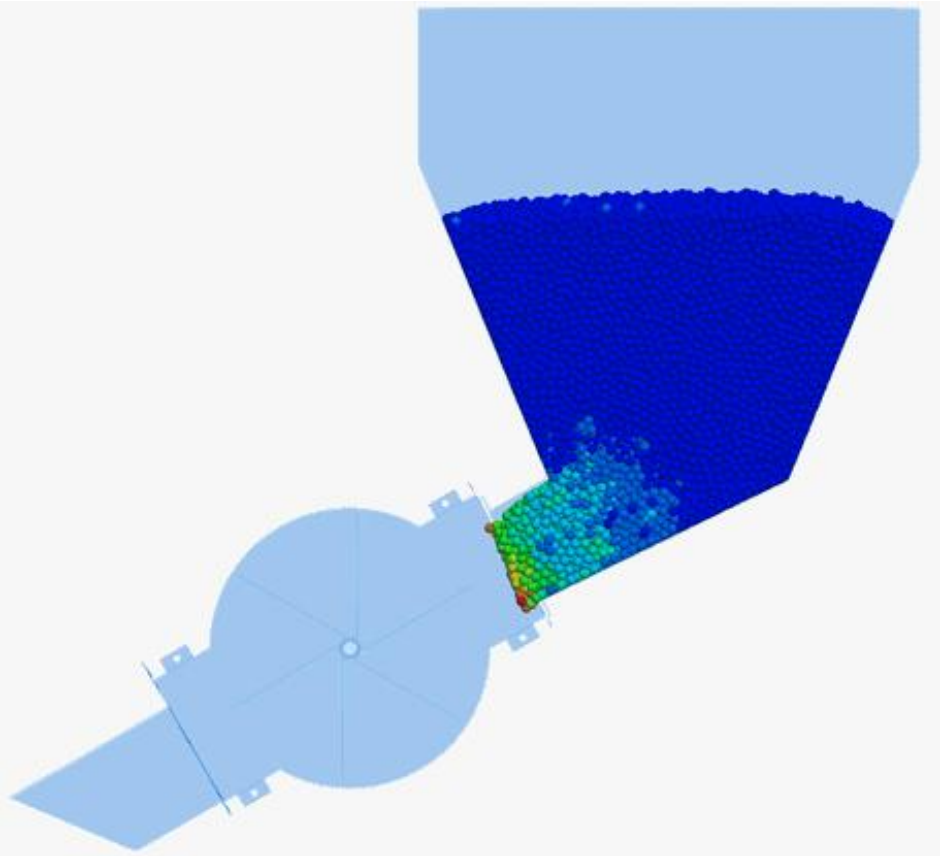


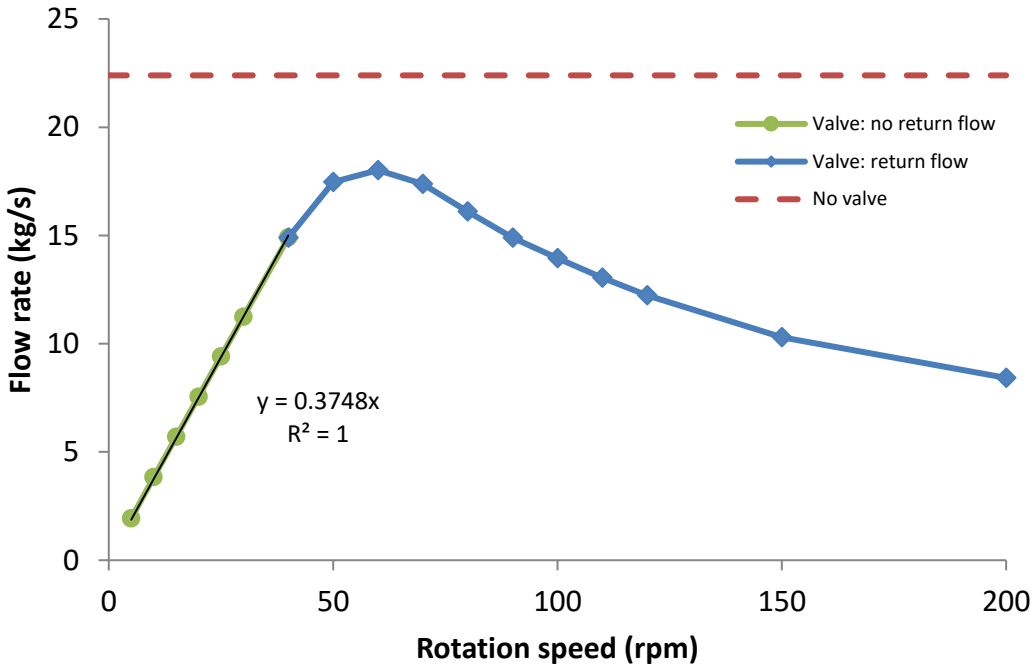
Corn grains



Bulk Materials Handling using DEM

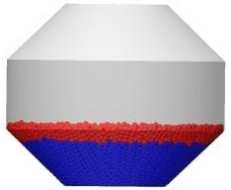
- Rotary valve

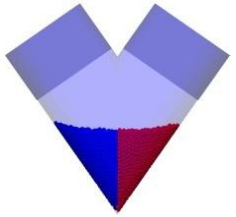


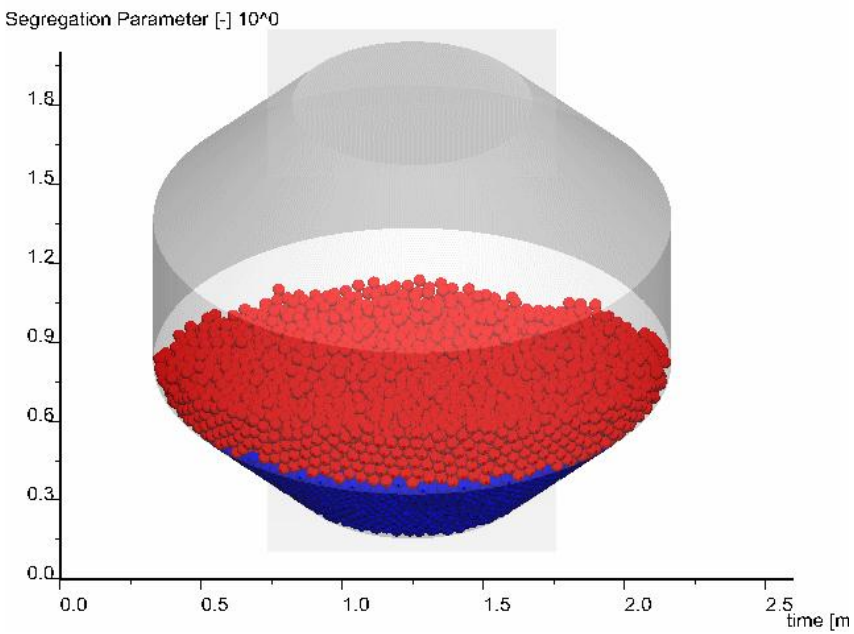


Bulk Materials Handling using DEM

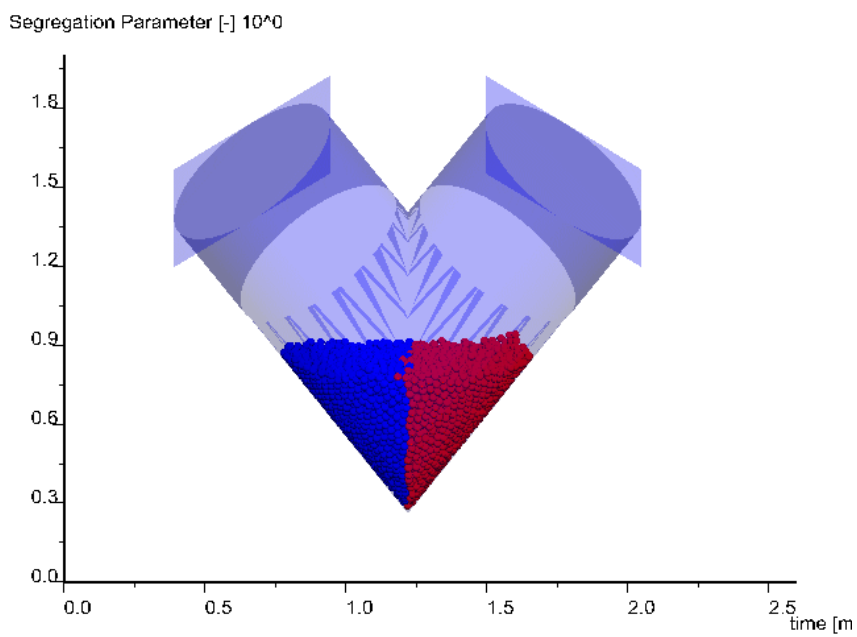
- Mixing and blending







Conical mixer

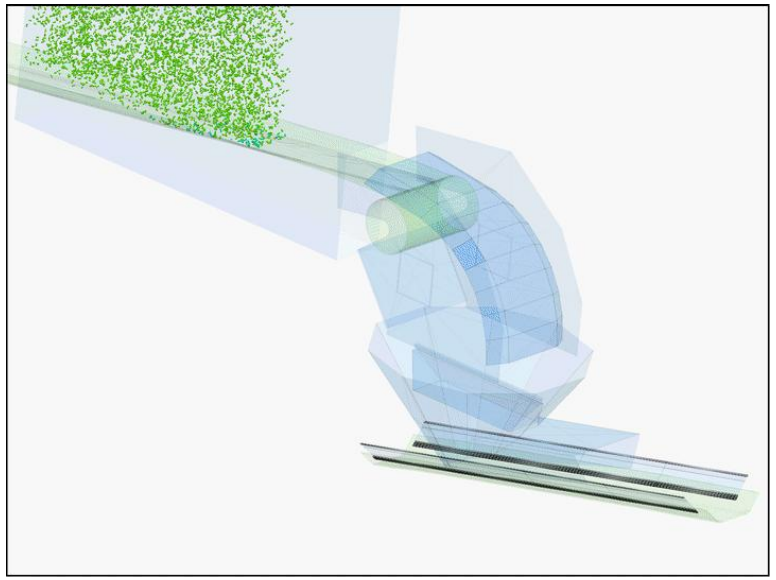


V-mixer

Bulk Materials Handling using DEM

- Belt conveyors and transfer chutes

Laboratory conveyor (corn grains)

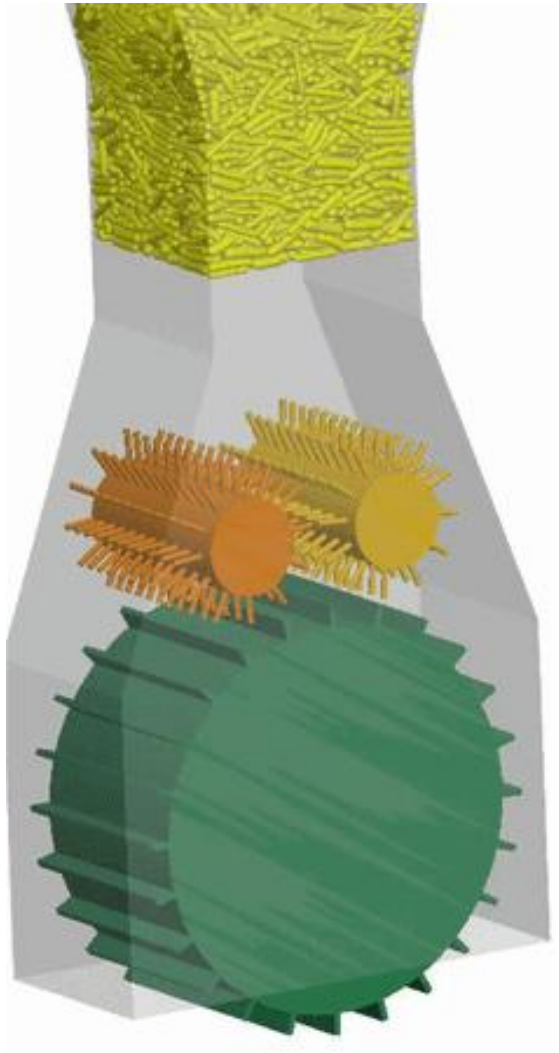


DEM modelling (corn grains)

Wet (cohesive) sand

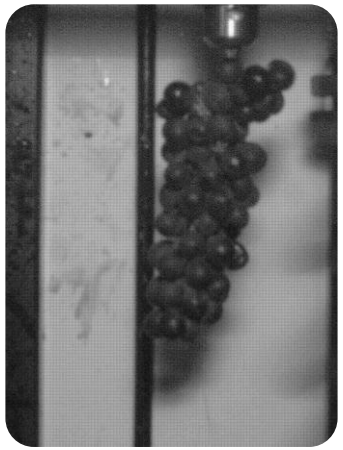
Bulk Materials Handling using DEM

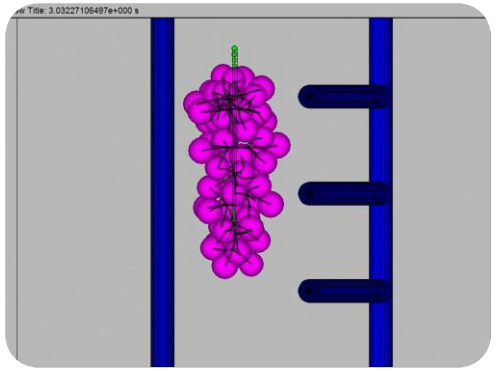
- Flexible particles (fibers)



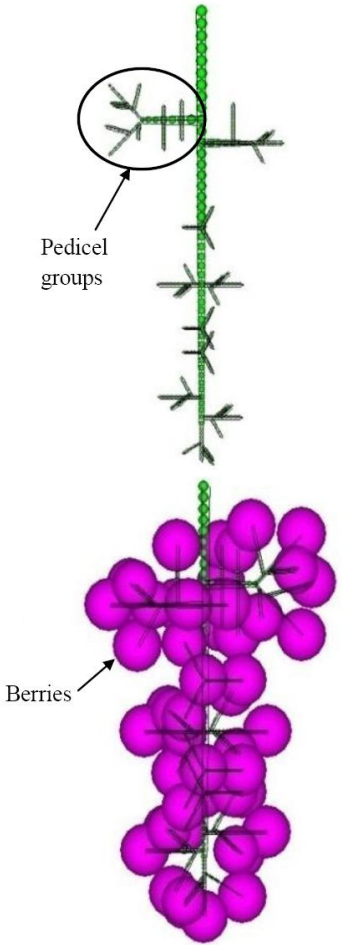
Bulk Materials Handling using DEM

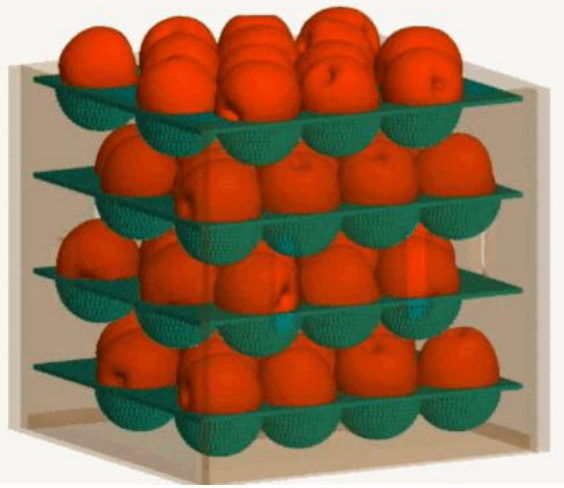
- Postharvest handling of fruit (soft particles with damage)



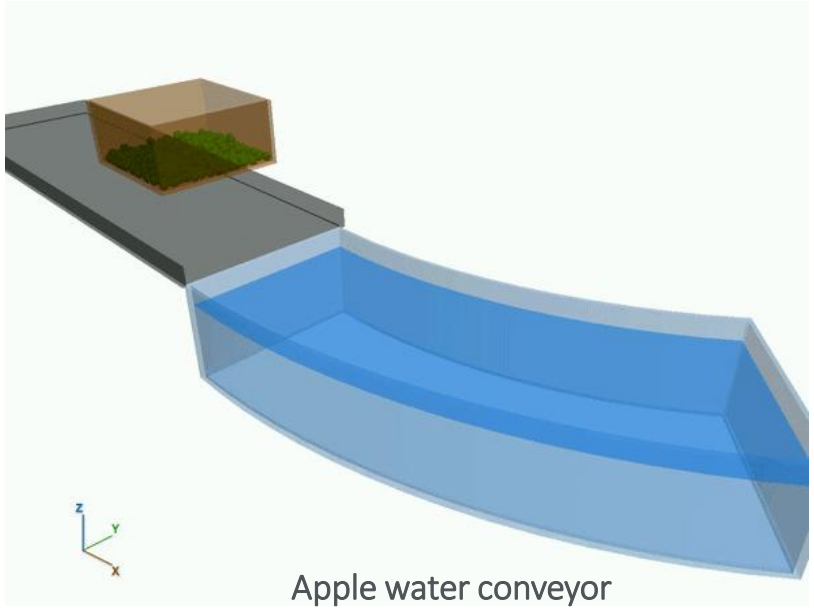


Destemming of grape berries





Apple packaging



Apple water conveyor

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Finite Element Method (FEM)

Structural Performance of Packaging using FEM

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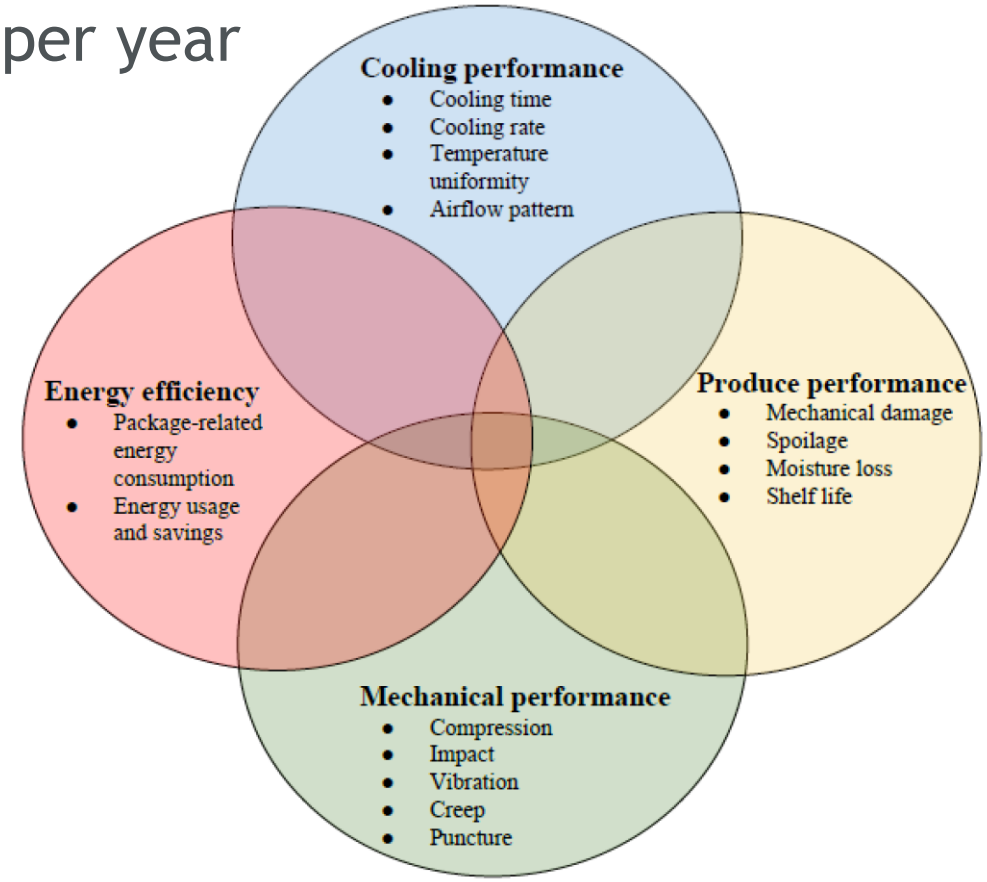
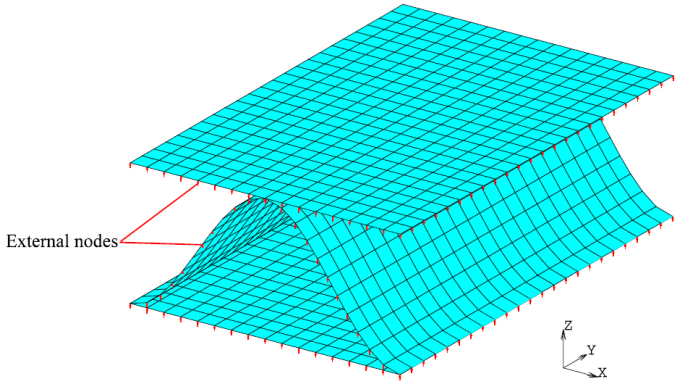
- Fruit is packaged, stored and transported in paperboard cartons (boxes)
- South Africa exports 300 million cartons of fruit per year

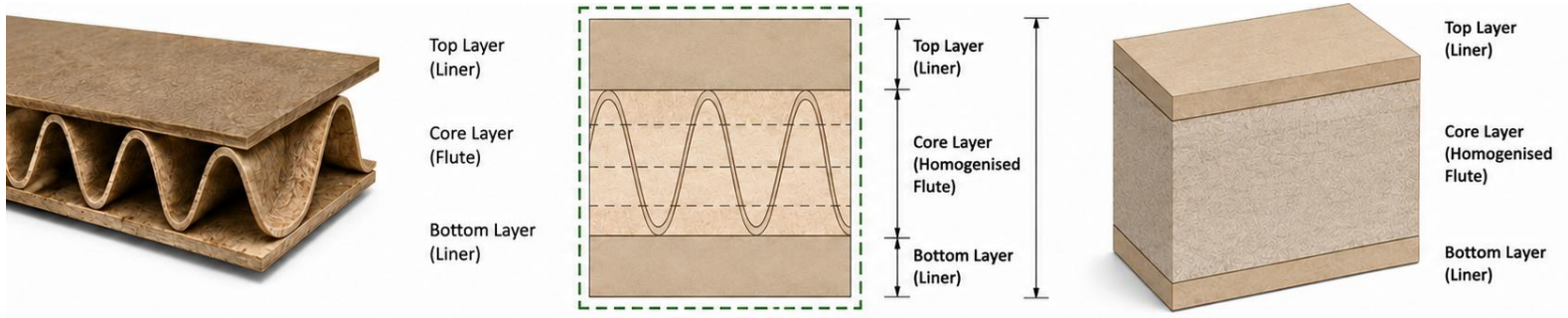


Structural Performance of Packaging using FEM

- Corrugated paperboard is a complex material
  - Sensitive to changes in temperature and humidity
  - Orthotropic properties
- FEM can be used as a design tool
  - Simplifying assumptions are needed to model a complete box
  - Inverse analyses and optimisation to determine material properties



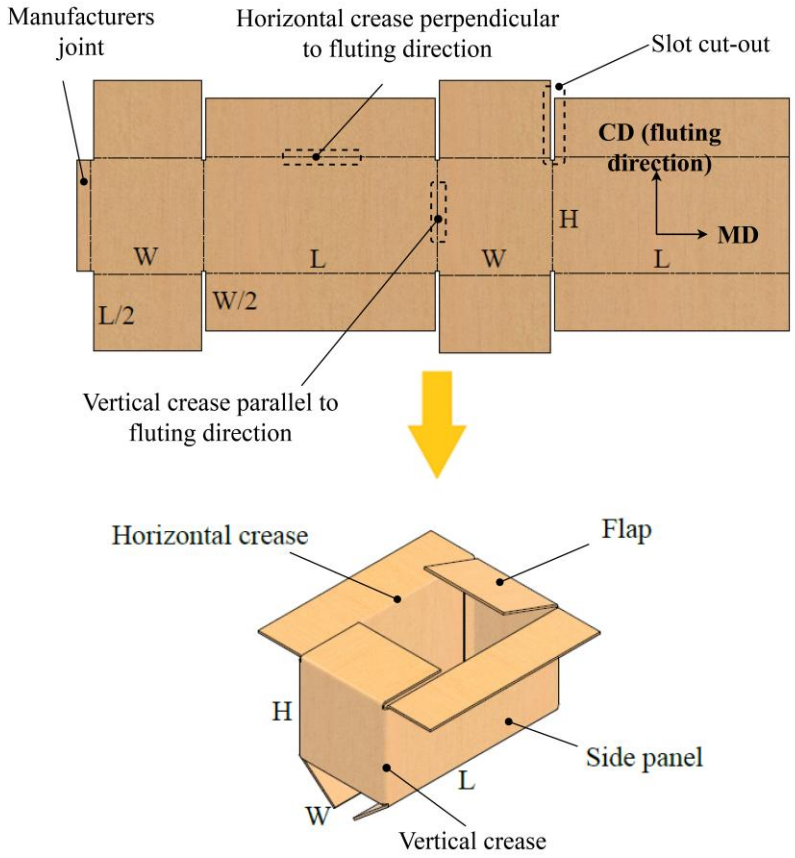
Detailed FEM model of the liners and fluting

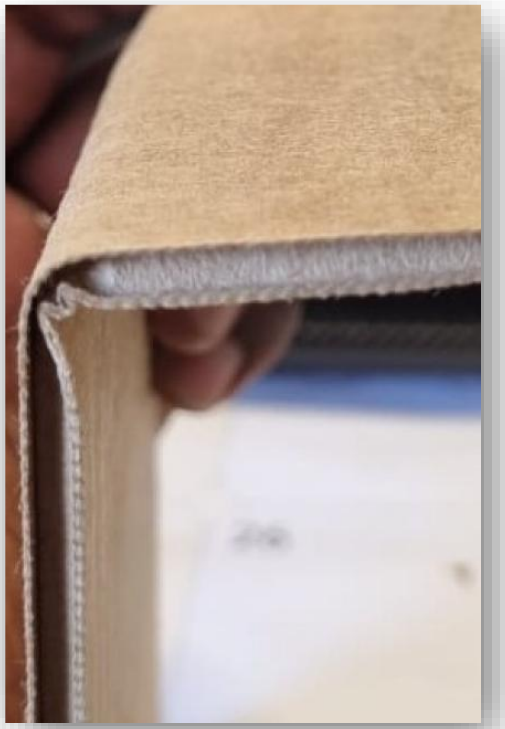


Simplifying the corrugated board to three solid layers with equivalent behaviour

Structural Performance of Packaging using FEM

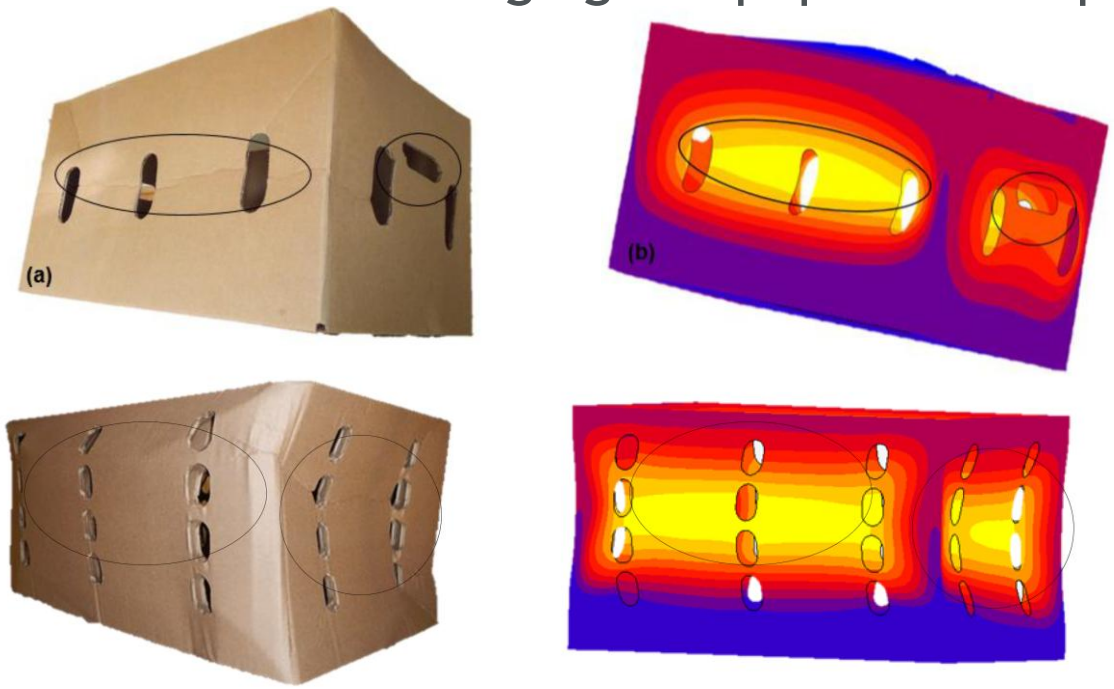
- Material testing

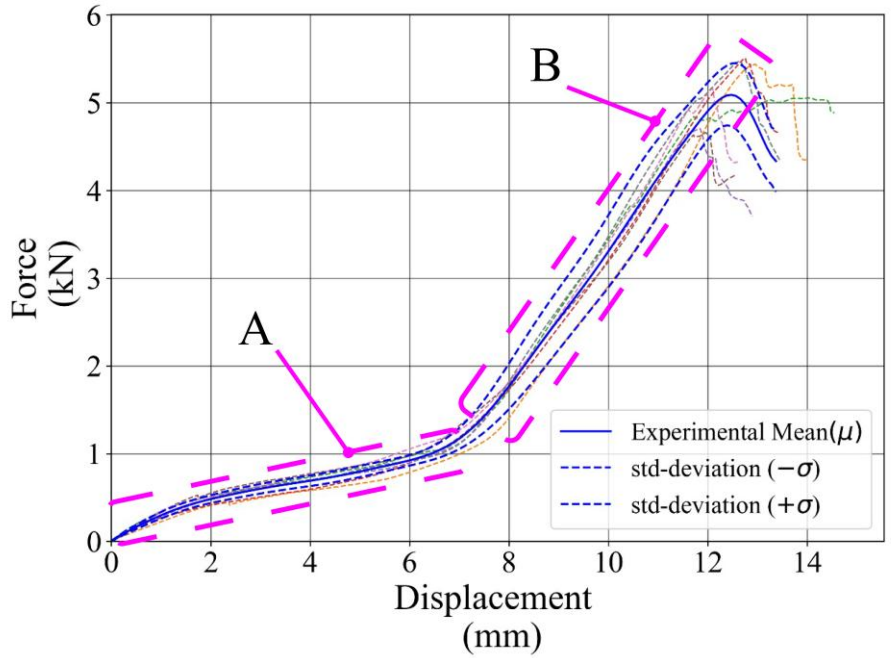




Structural Performance of Packaging using FEM

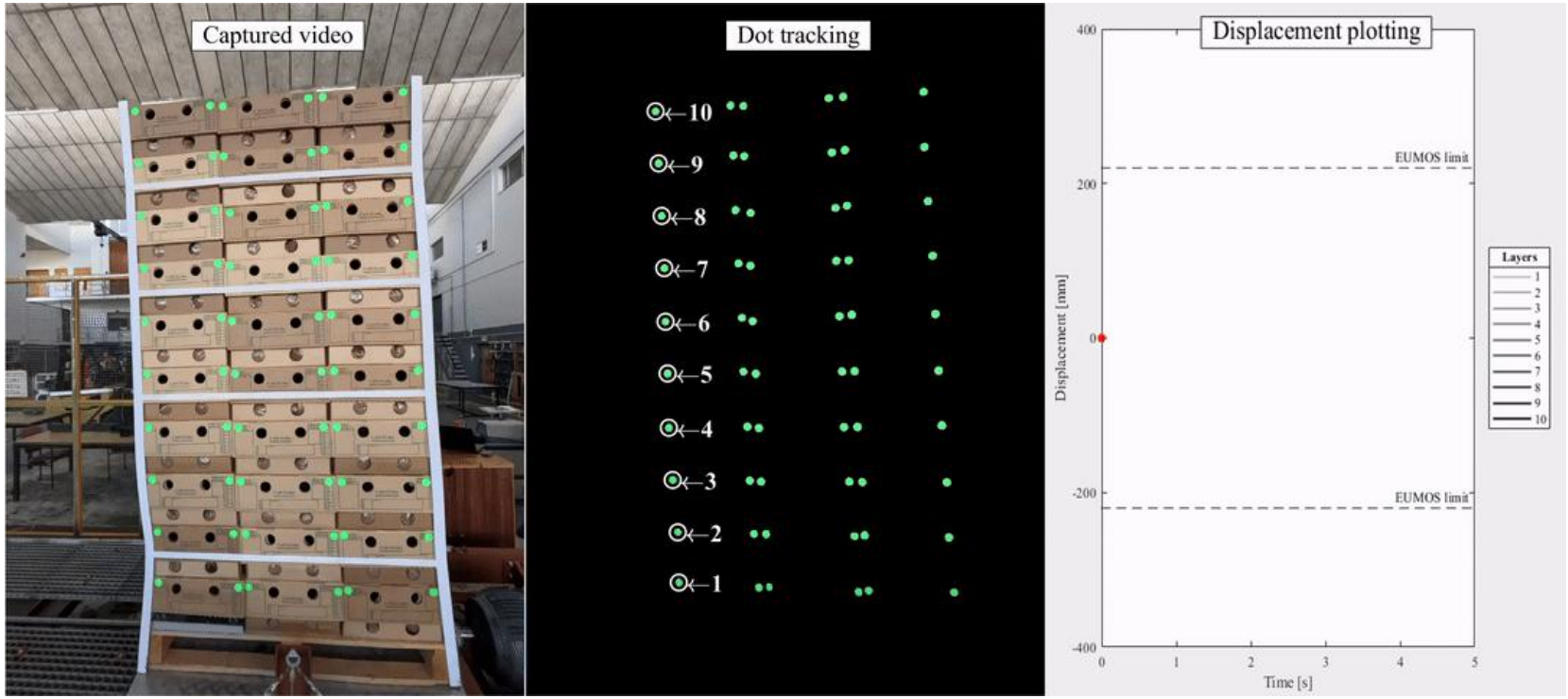
- A FEM model can predict:
  - The carton load-displacement response under various load conditions
  - The effects of ventilation hole size and position
  - The effects of changing the paperboard specification





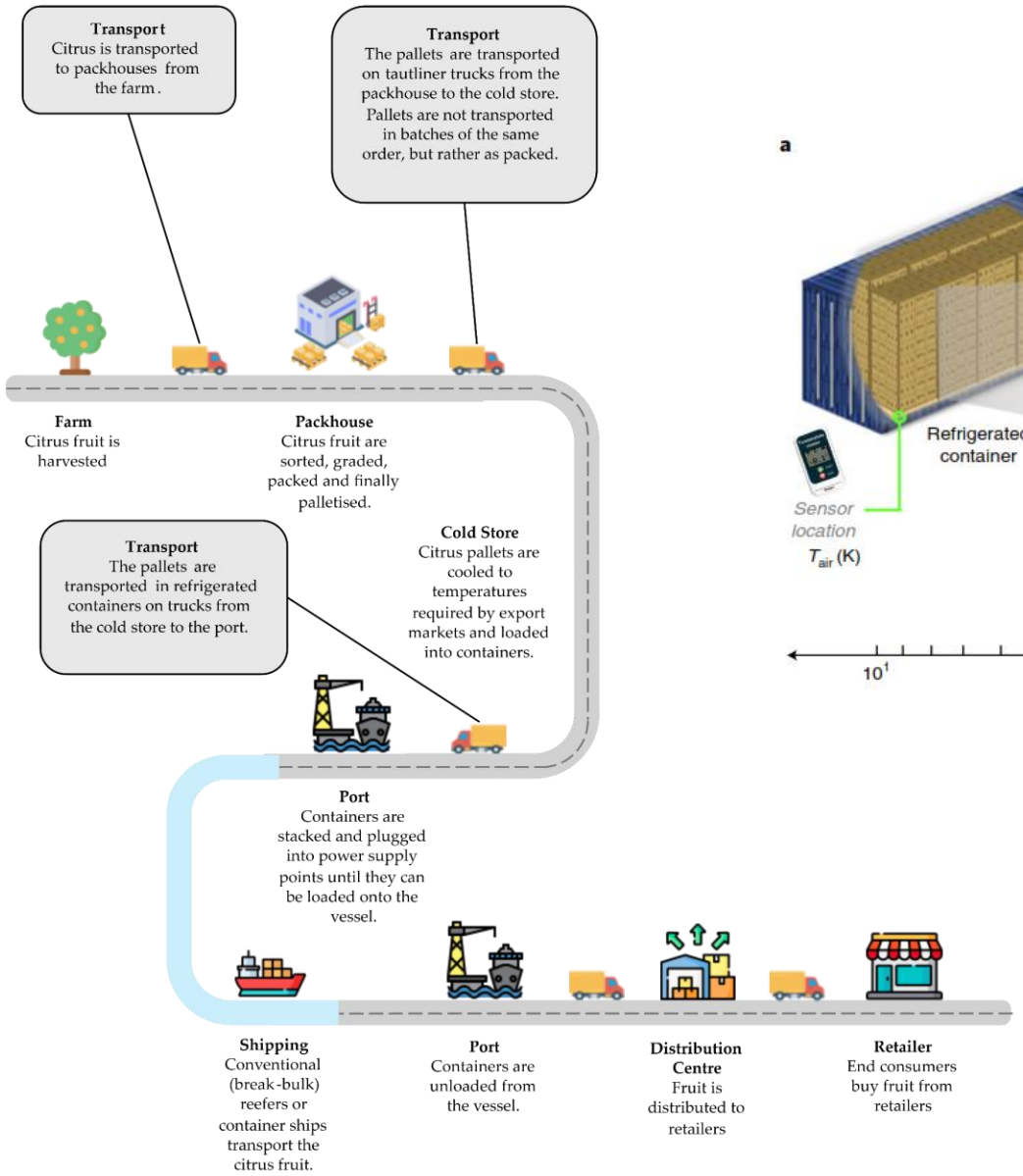
Structural Performance of Packaging using FEM

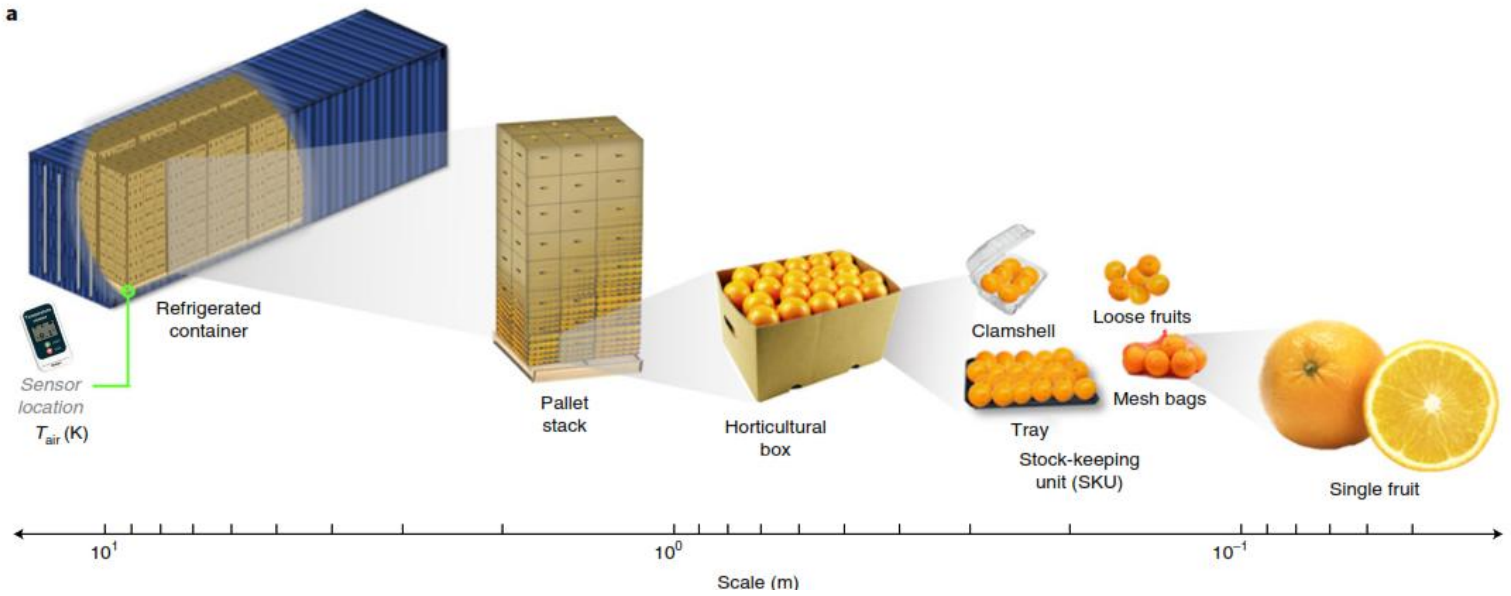
- Pallet stability testing
  - Lateral acceleration/deceleration of a palletised stack



Integrated Cold Chain Management
&
Computational Fluid Dynamics (CFD)

The Citrus Supply Chain



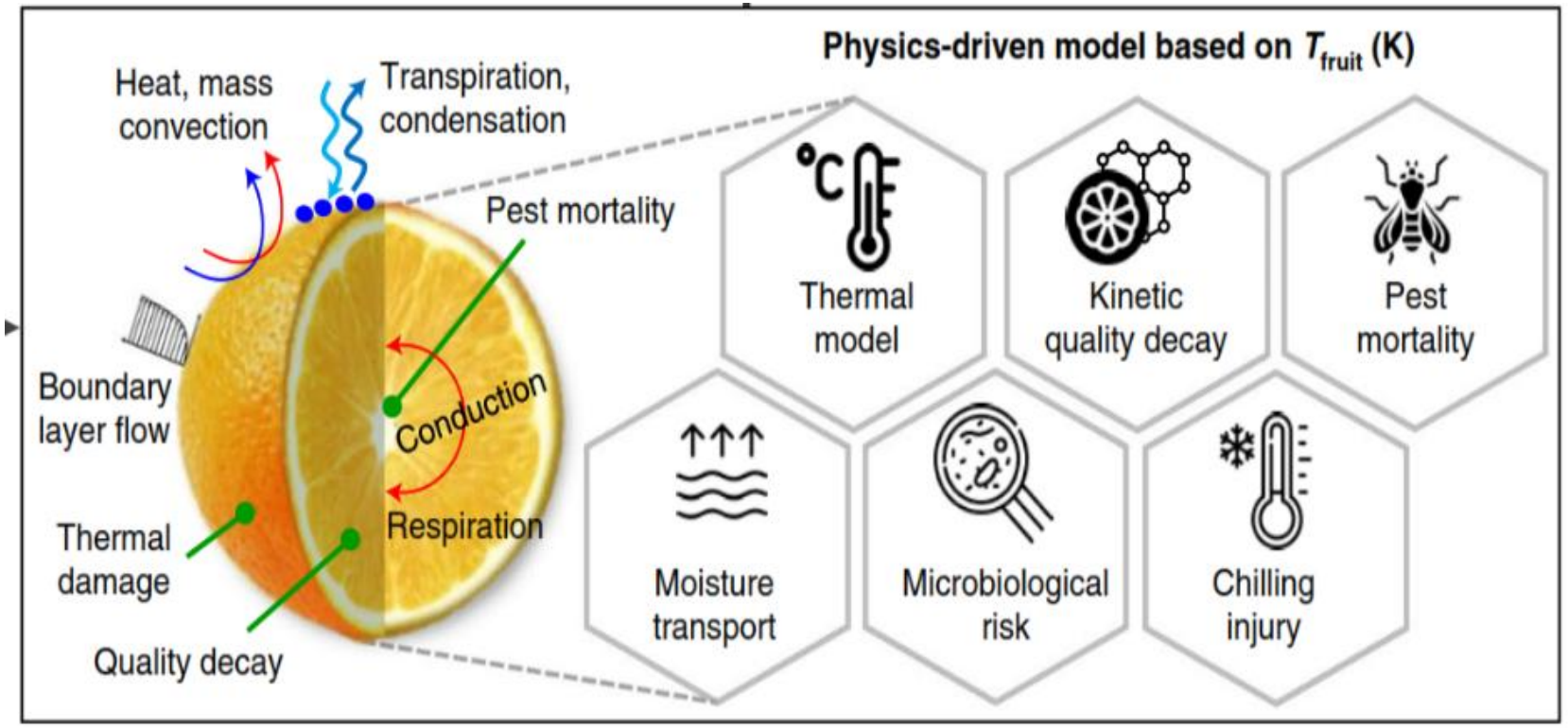


Factors to consider:

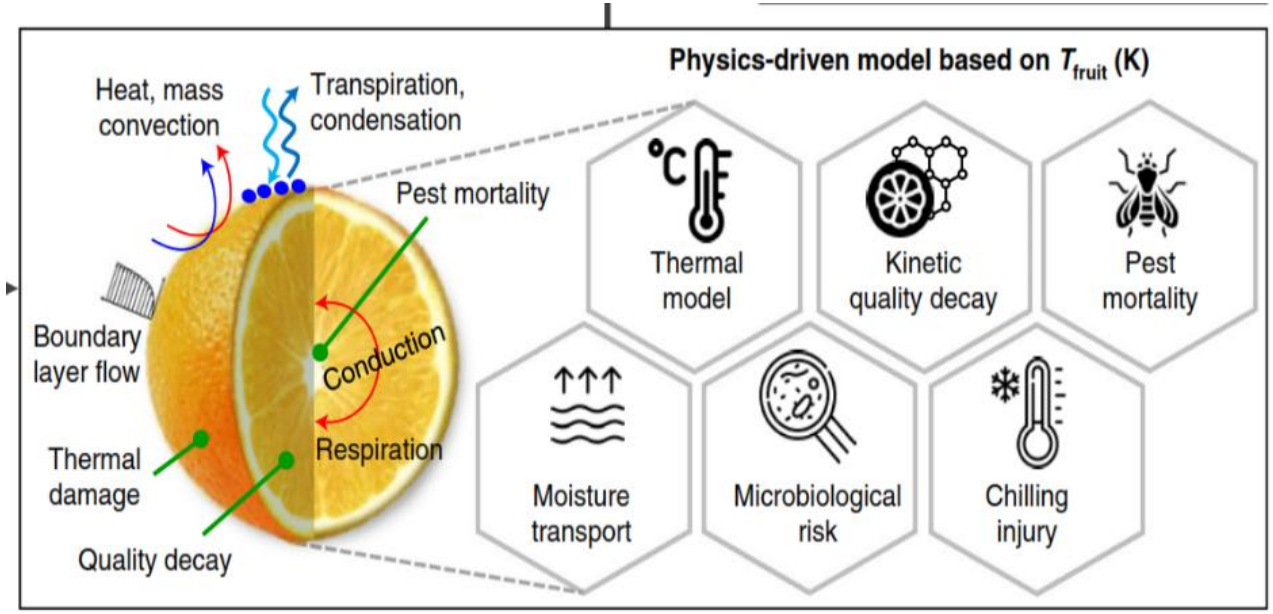
1. Marketing - drives all decisions, highly sporadic
2. Port infrastructure - Not playing ball
3. Major variations in fruit quality development

The Plan: Cold Chain Digital Twin

- Most shipments are overkill
  - SA ports are some of the most inefficient in the world
  - Transit durations are often unnecessarily long
  - Majority of consignments massively overshoot cooling requirements
  - Exports are profitable, but losses are significant



First Model: Refrigerated Container



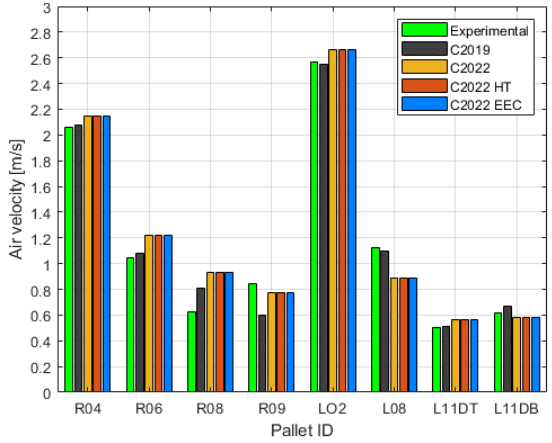
- Inputs: Sensor data (temperature, humidity)
- Simulations: Track moisture loss, chilling injury, pest mortality, and remaining shelf life
- Outputs: Actionable insights on fruit quality and marketability

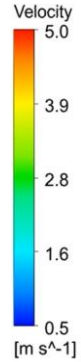
Shrivastava, C., Berry, T., Cronje, P., Schudel, S., & Defraeye, T. (2022). Digital twins enable the quantification of the trade-offs in maintaining citrus quality and marketability in the refrigerated supply chain. *Nature Food*. https://doi.org/10.1038/s43016-022-00497-9

Container Airflow Dynamics

- Fully characterized
  - Front of container (refrigeration unit)
  - High airflow rates (~0.1 m/s)
  - Poor ventilation can concentrate cold airflow here
  - Back of container (door)
  - Low airflow rates at the door (~0.01 m/s)
  - Poor ventilation = lower flow rates (~0.001 m/s)

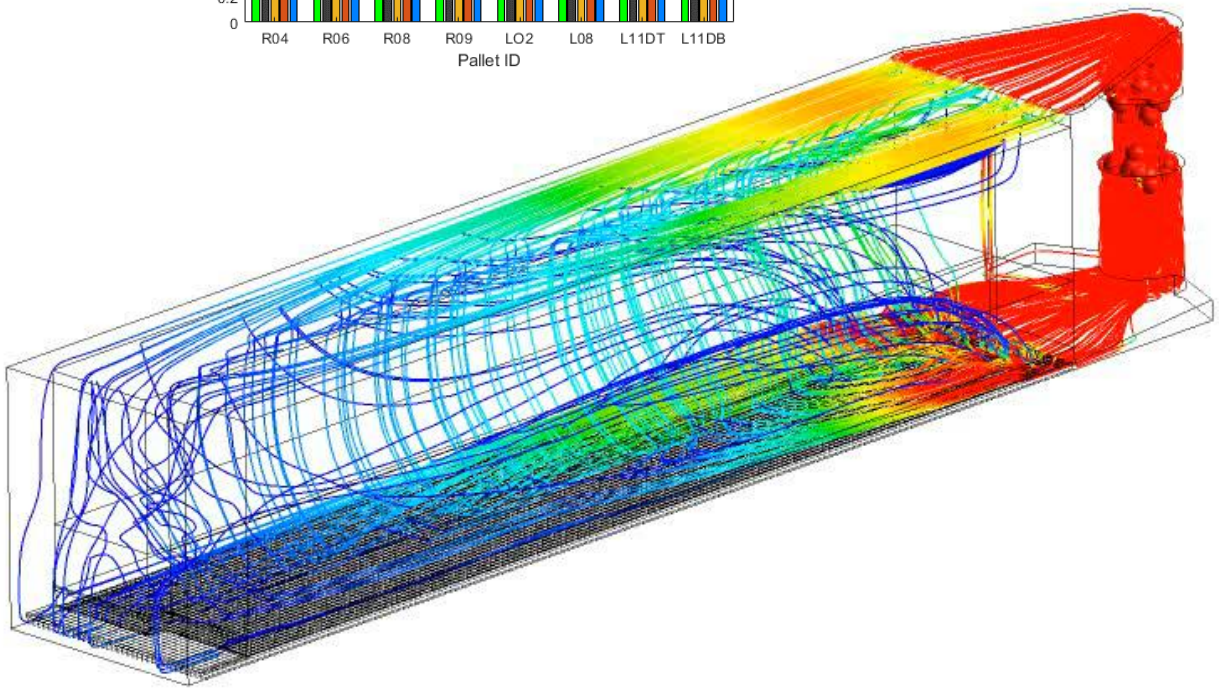
Validation results: Excellent





- Solutions

1. Container flow optimisation kits
2. High-porosity packaging



Airflow Optimisation Kits

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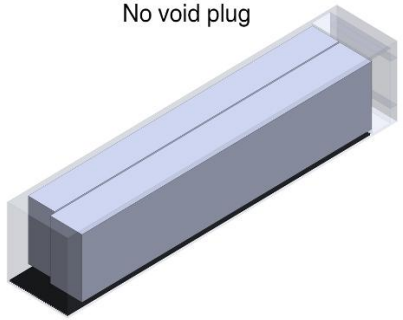
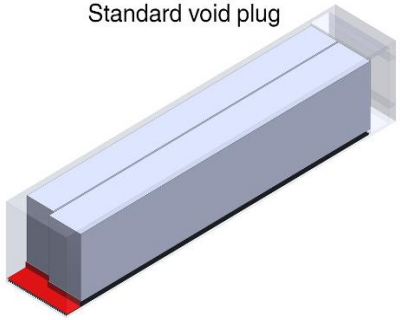
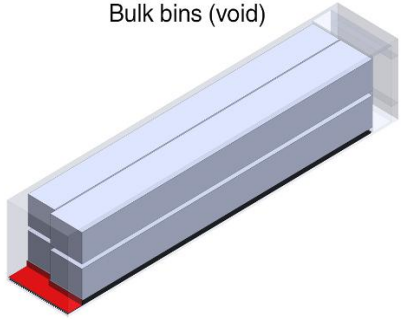
No void plug



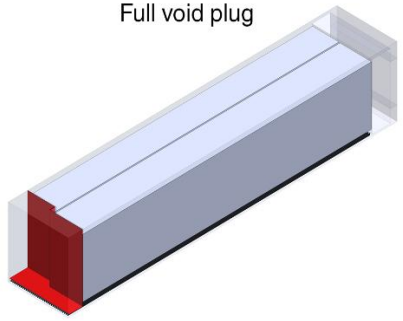
Standard void plug



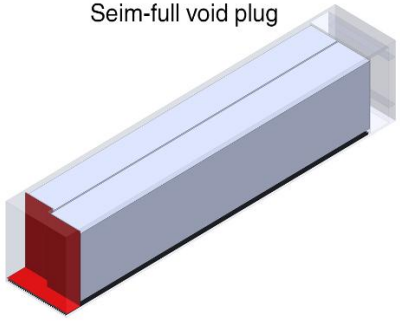
Bulk bins (void)



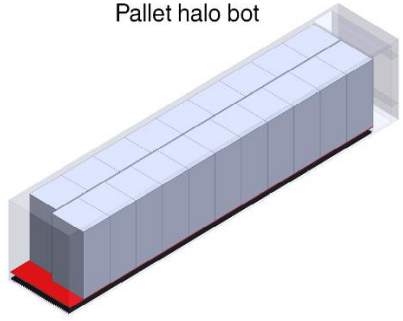
Full void plug



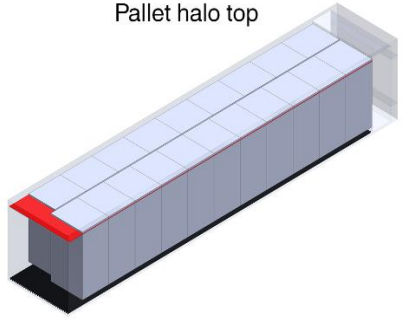
Seim-full void plug



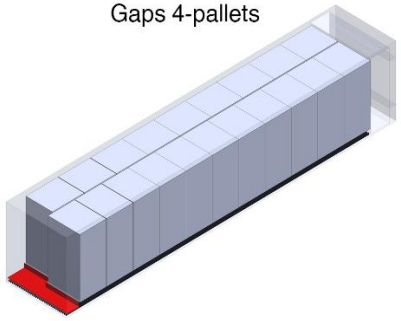
Pallet halo bot



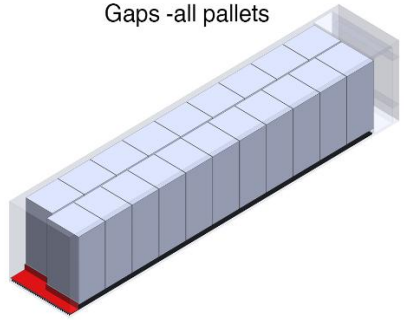
Pallet halo top



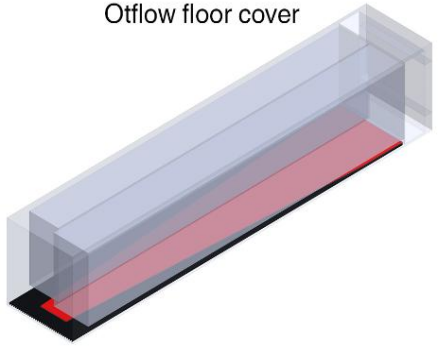
Gaps 4-pallets



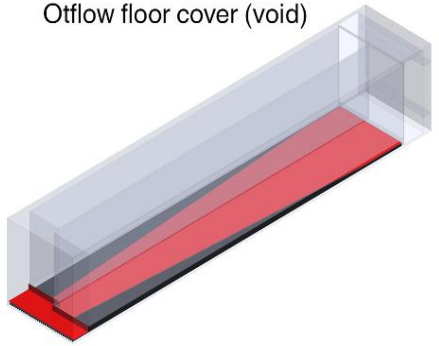
Gaps -all pallets



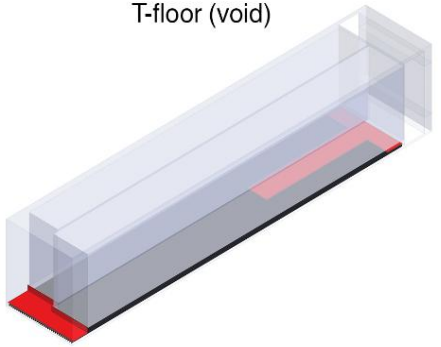
Otflow floor cover



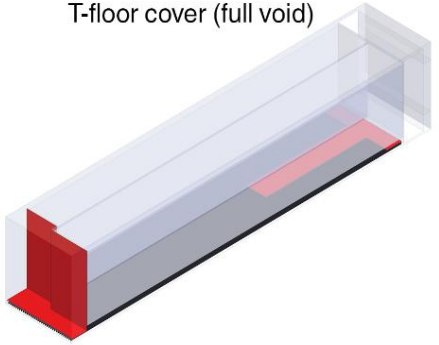
Otflow floor cover (void)



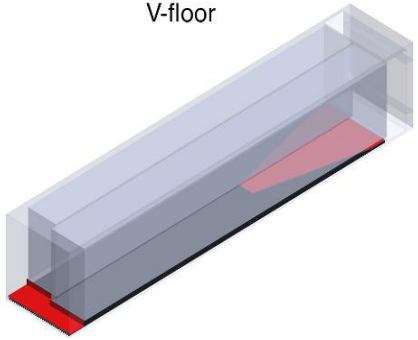
T-floor (void)



T-floor cover (full void)



V-floor

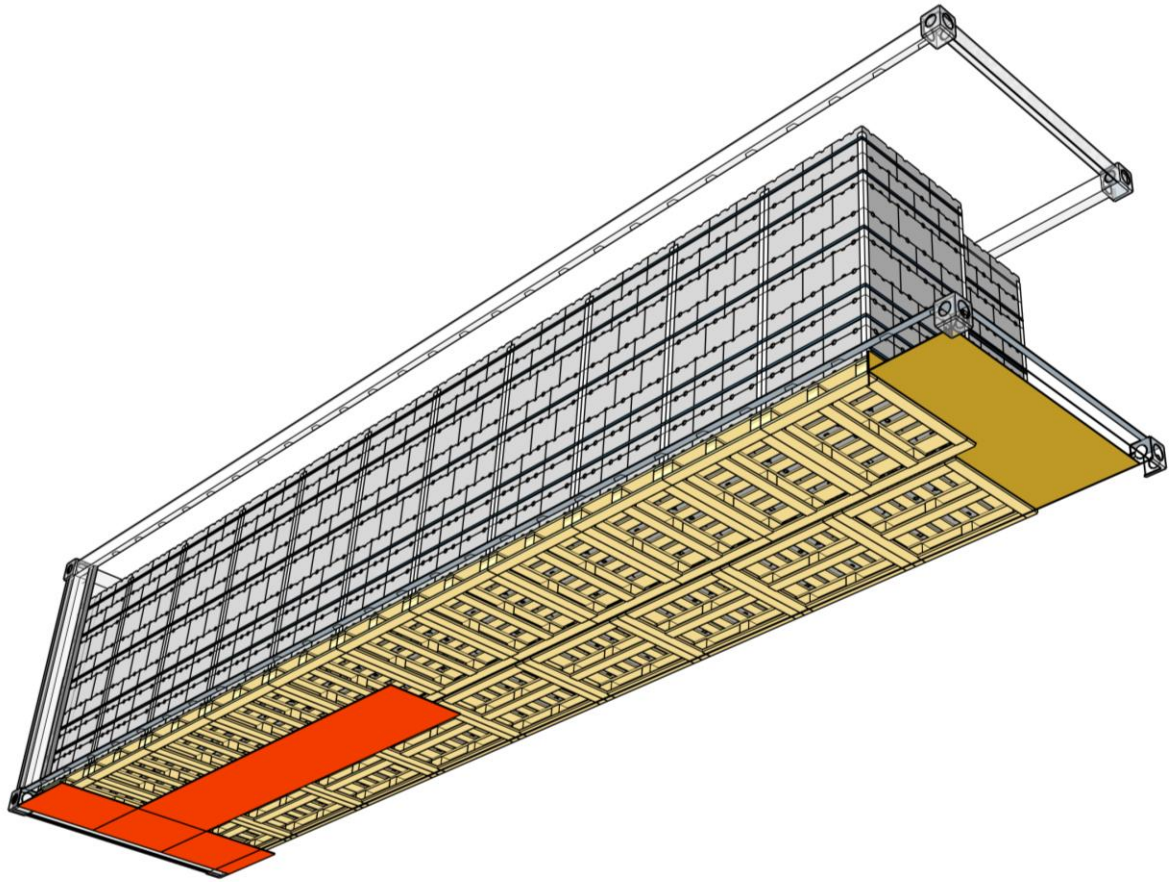


T-Floor

- Manufacturing support
  - Anyone can manufacture
  - Reefer mat EasyCO (mike Cohen) make a good product
- Experimentally proven to create more uniform cooling in the container
  - Improves cooling near the door

easyCO & Wave Paper

Reefer Mat™ Sales Brochure



Commercial solution!

Resolving Optimal Precooling Protocols for Citrus

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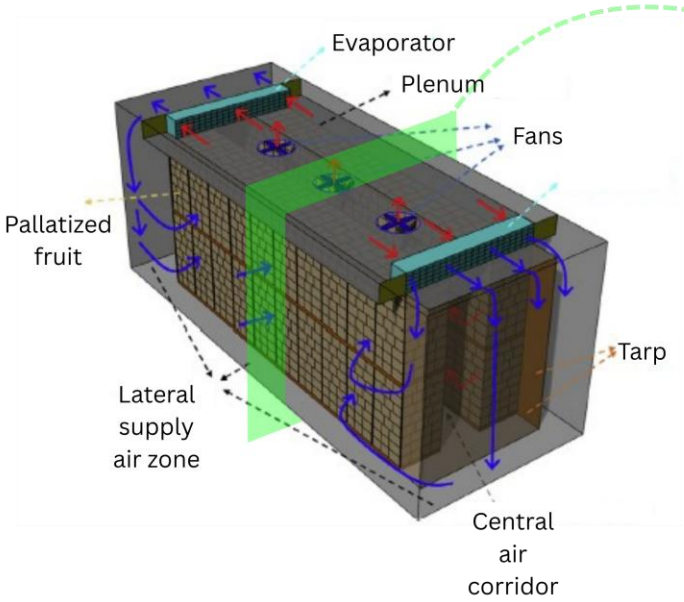
Phase 1: Characterising commercial cooling dynamics



Commercial FAC facility

Adapted from Wu et al., (2018)

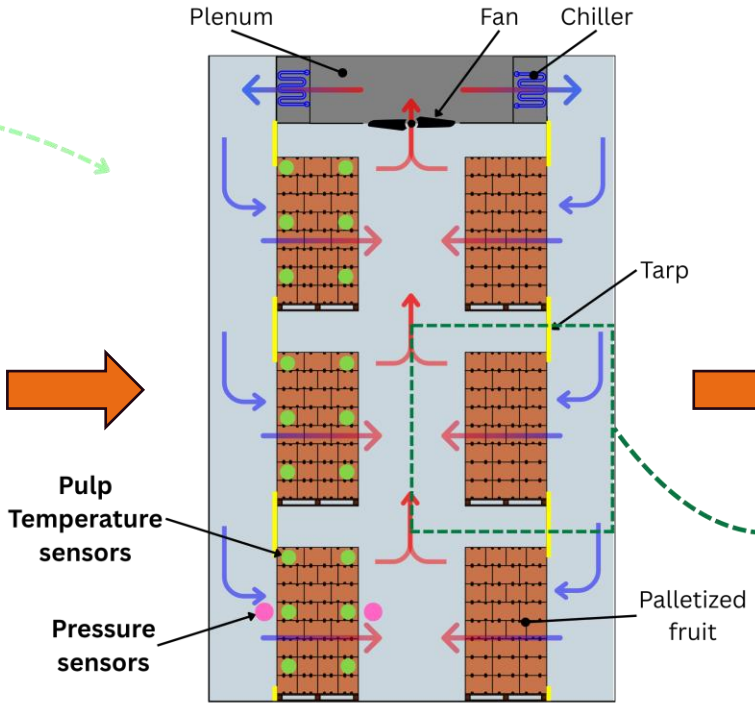
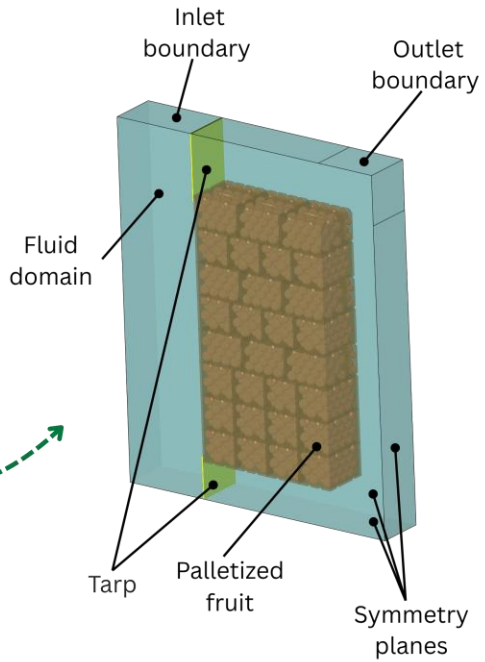
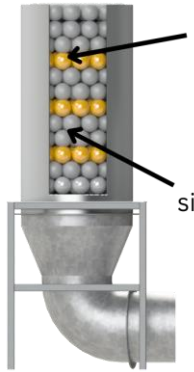


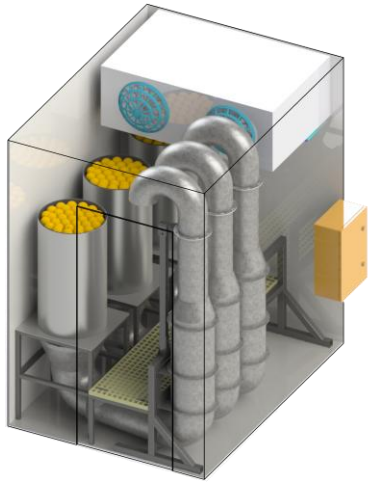
Illustration of FAC facility & sensor placement

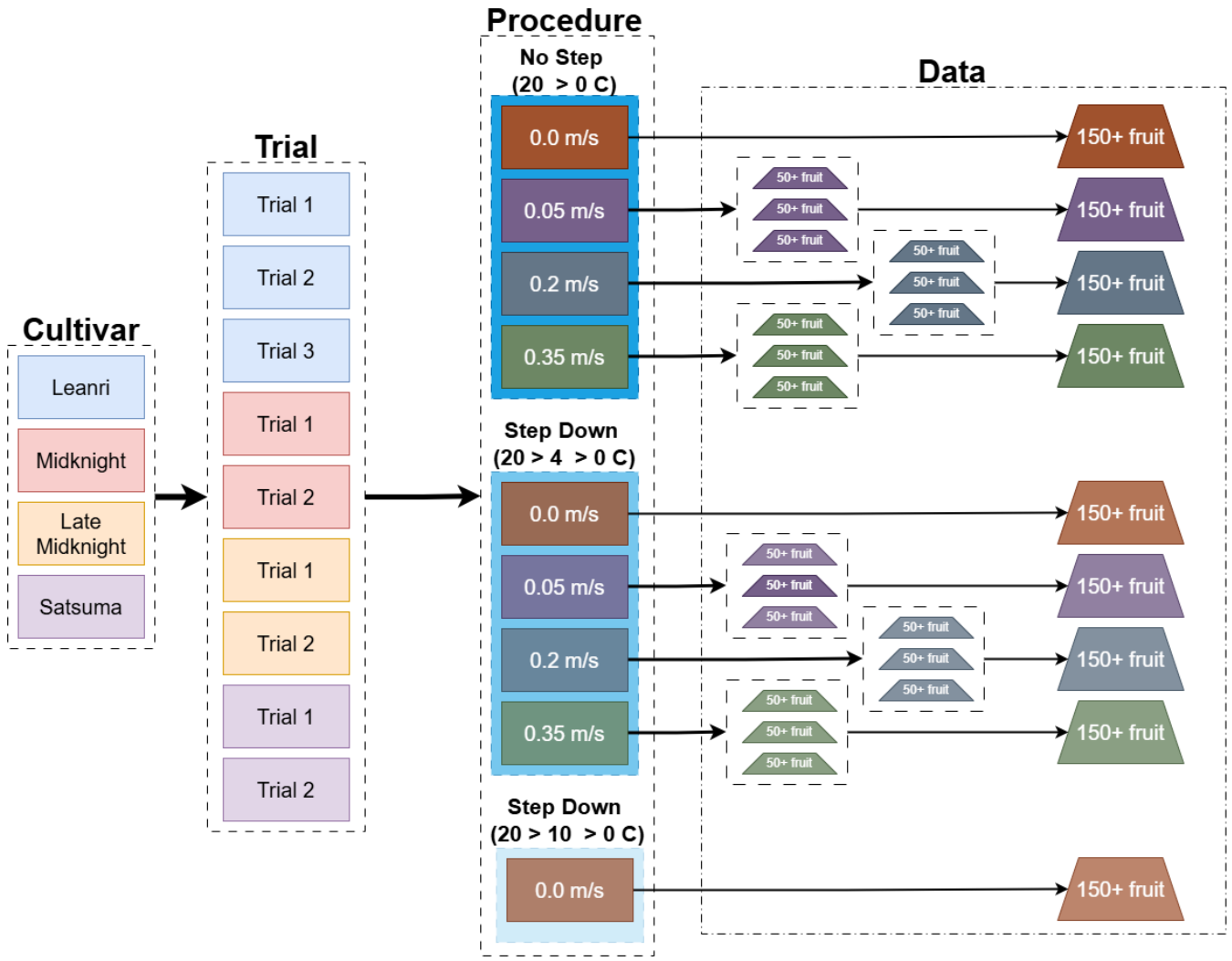


CFD model representation

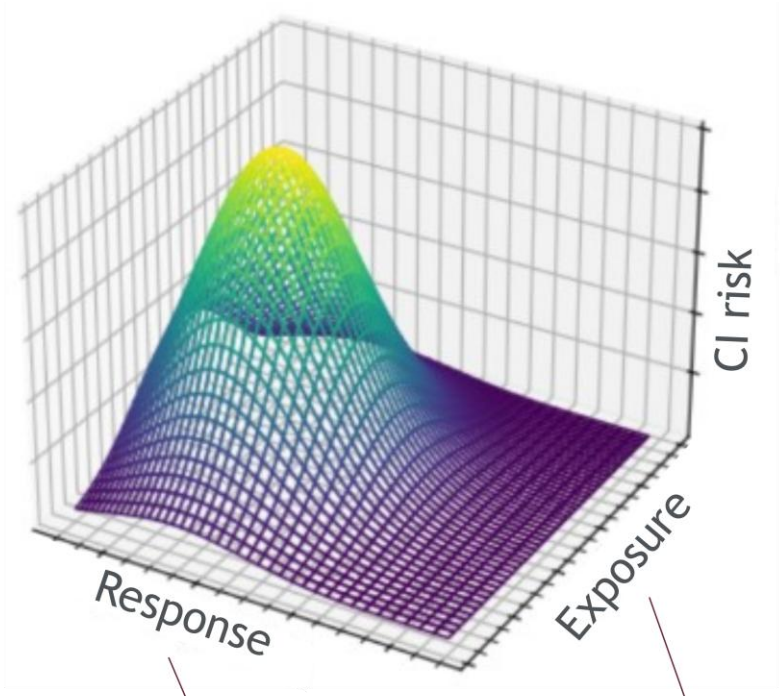
Phase 2: Laboratory precooling setup – Trial procedure







Phase 3: Predictive modelling



- Lag factor
- Max slope
- Time to threshold
- Time below threshold

- Temperature
- Velocity

- CI risk expressed as a function of exposure history
- Combines thermal and flow variables from experiments and CFD
- Goal: link precooling protocol directly to CI risk

Stellenbosch
UNIVERSITY
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Thank you
Enkosi
Dankie

Photo by Stefan Els