Use of avocado geometry and porosity for rapid packaging design optimisation



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Porosity and fruit geometry

https://theavoclub.com.au/product/the-avo-addict-10kg-box/

$$Porosity = \frac{Volume\ of\ voids}{Volume\ of\ box}$$

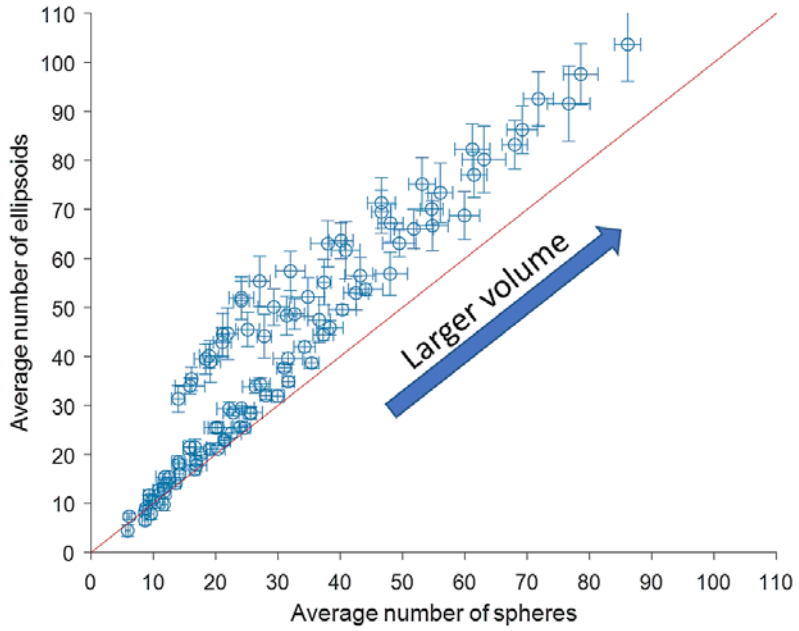
Factors that can be influenced by porosity

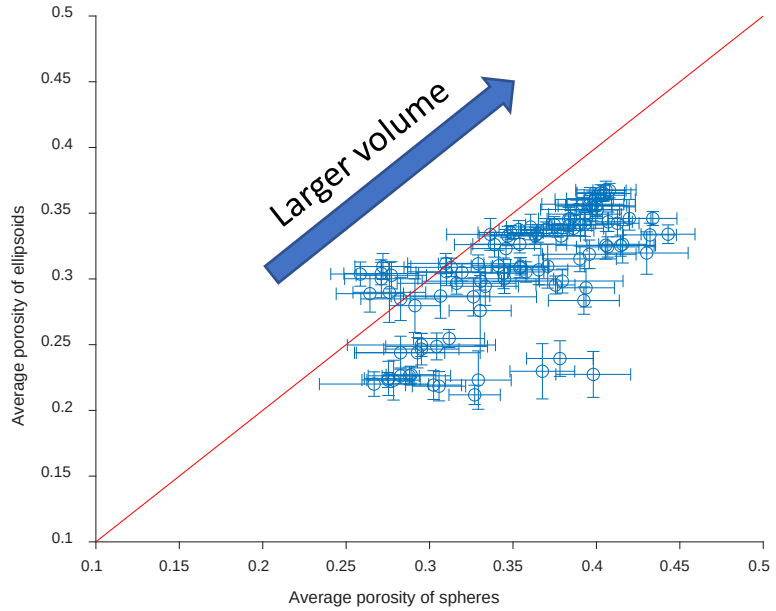
- Packing efficiency
  - Economical and environmental efficiency
  - Indication of how volume is utilised (optimum use)
- Cooling performance
  - Affected by sizes or shapes between fruits
  - Homogeneity

Comparison of porosity prediction from assumed shapes

Spheres

Ellipsoids

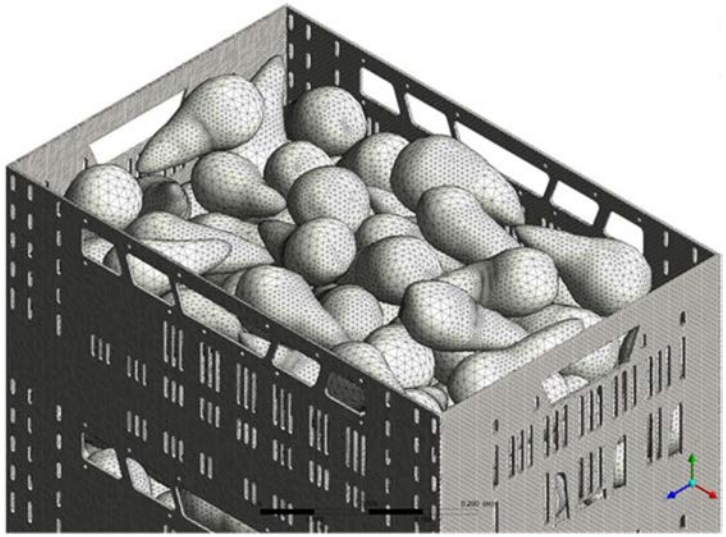




LIMITATIONS ASSUMING FRUIT SHAPE AND SIZE

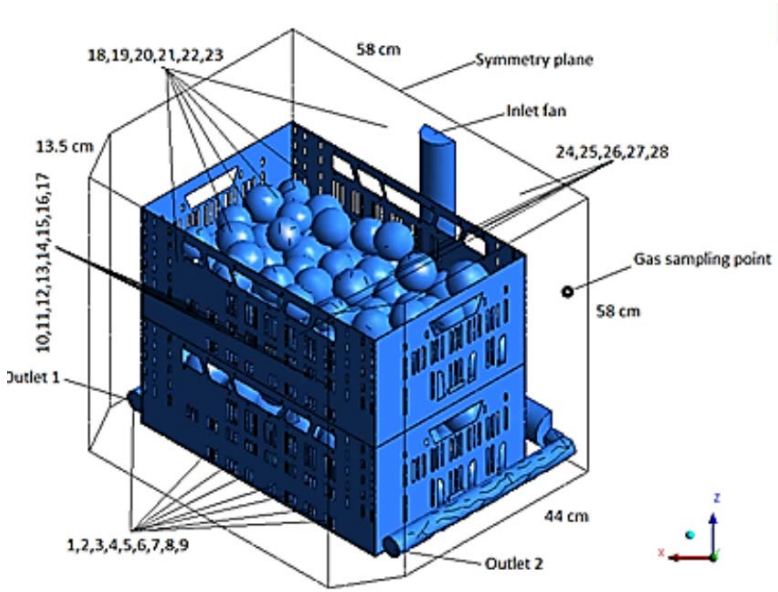
Existing work on fruit geometry and porosity (digital simulations)

Pears



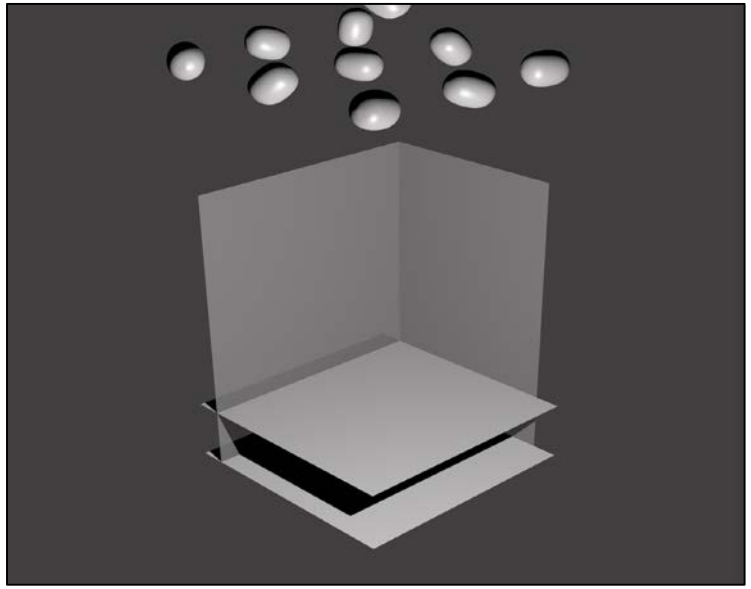
Delele, M. A. et al (2019). Spatial distribution of gas concentrations and RQ in a controlled atmosphere storage container with pear fruit in very low oxygen conditions. *Postharvest Biology and Technology*, *156*, 110903.

Apples



Bessemans, N., et al (2015, October). A computational fluid dynamics model of the spatial and temporal gas distribution in a storage container for apple fruit. In V International Symposium on Applications of Modelling as an Innovative Technology in the Horticultural Supply Chain-Model-IT 1154 (pp. 185-192).

Kiwifruit



Olatunji, J. R., et al (2020). Reconstruction of kiwifruit fruit geometry using a CGAN trained on a synthetic dataset. *Computers and Electronics in Agriculture*, *177*, 105699.

Proposed methodology

Data collection

Application of porosity

Practical applications

Digitalisation of avocados → Simulation of Volume filling → Estimation of porosity and fruit number → Prediction of properties based on porosity → Packaging design

$$P = \frac{Volume\ of\ voids}{Volume\ of\ box}$$

- Equivalent heat transfer properties

- Packaging optimisation
- Sensitivity analysis

Three-dimension scanning of avocados

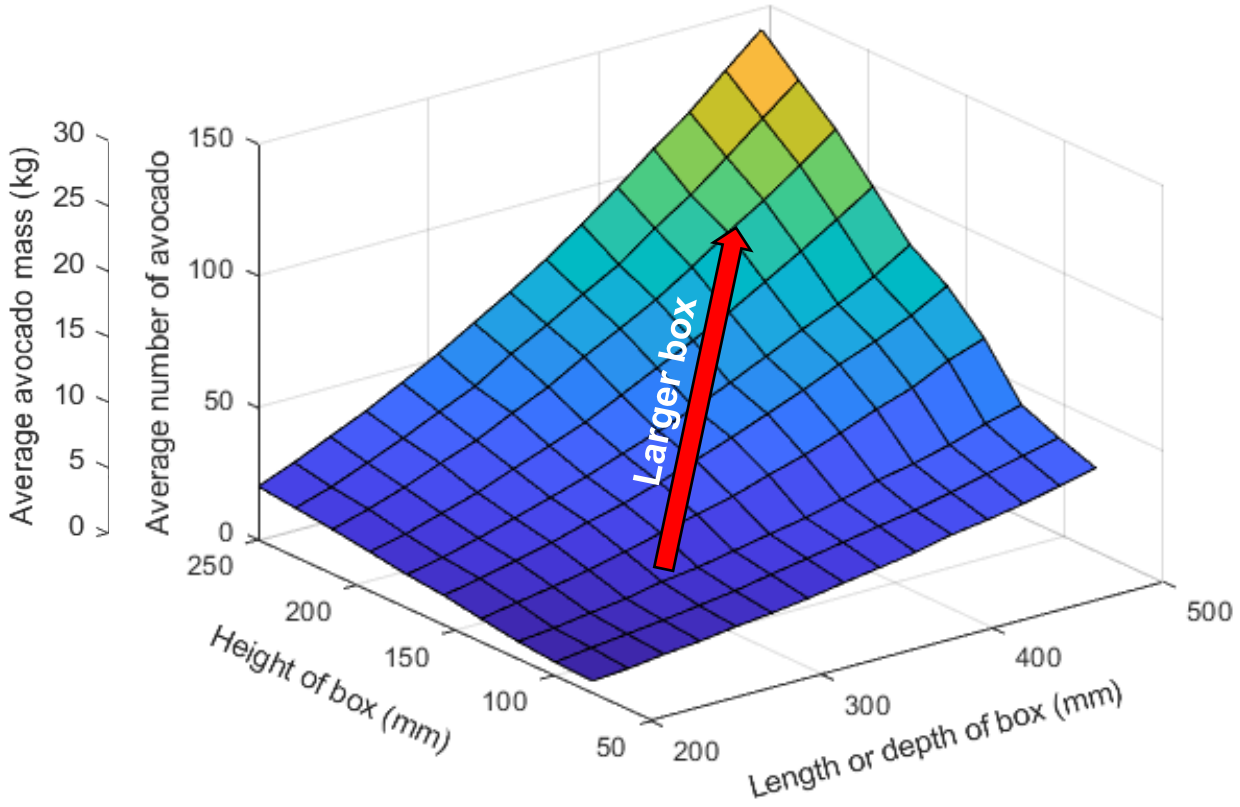
Digitalisation of avocado geometry

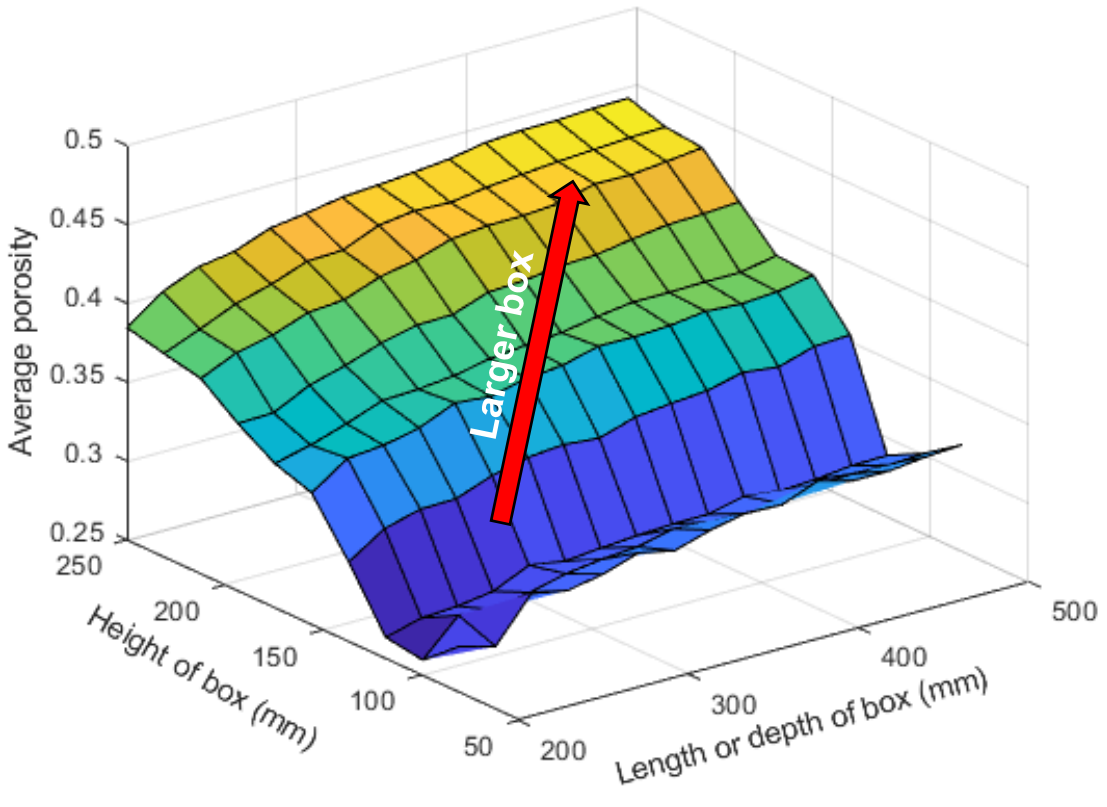
Random box filling

- Three-dimensional scanning conducted on 109 Hass avocados (3D shinning scanner)
- Fruit library was augmented to reproduce 2,300 fruit
- Random fruit size was selected for scanning
- Avocados were weighted to estimate density

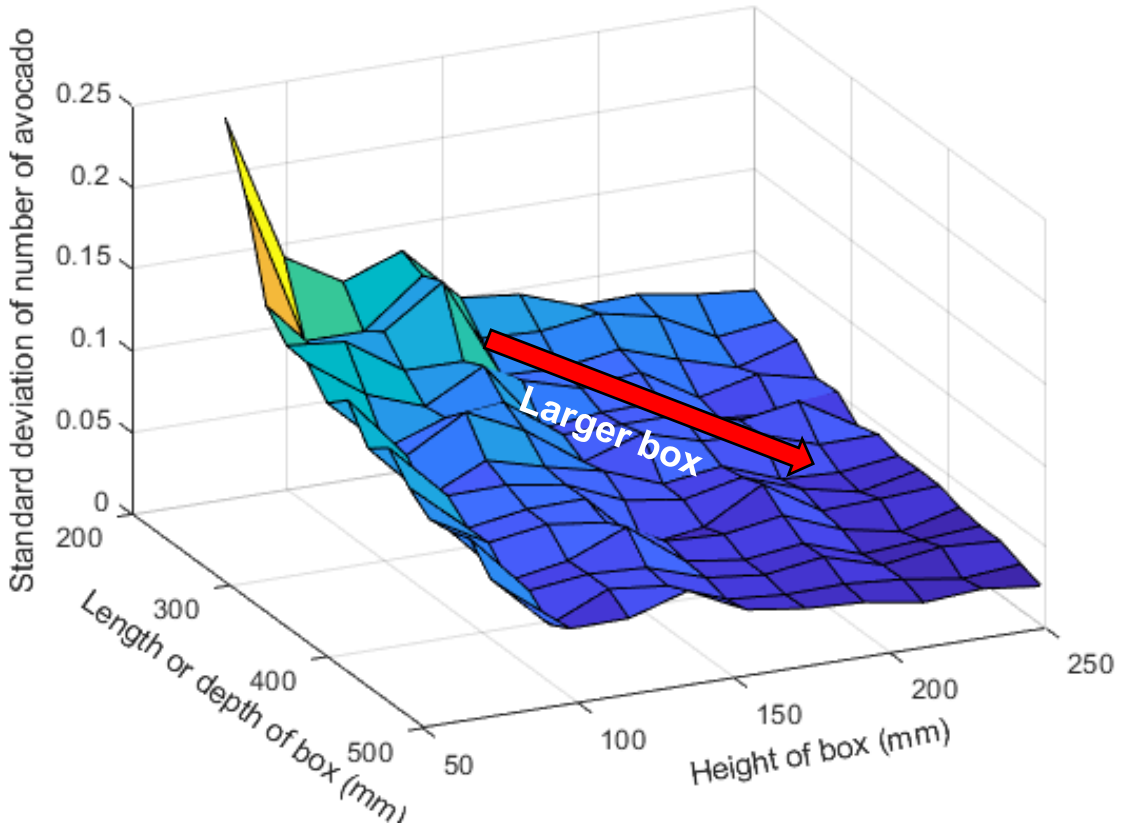
- From the library, the fruit was randomly placed in a given box design (Blender Software)
- 150 volumes (50 iterations per box dimension)
- The number of fruit and the total weight of the box was recorded
- Porosity as the ratio between the total volume of fruit against the volume of boxes

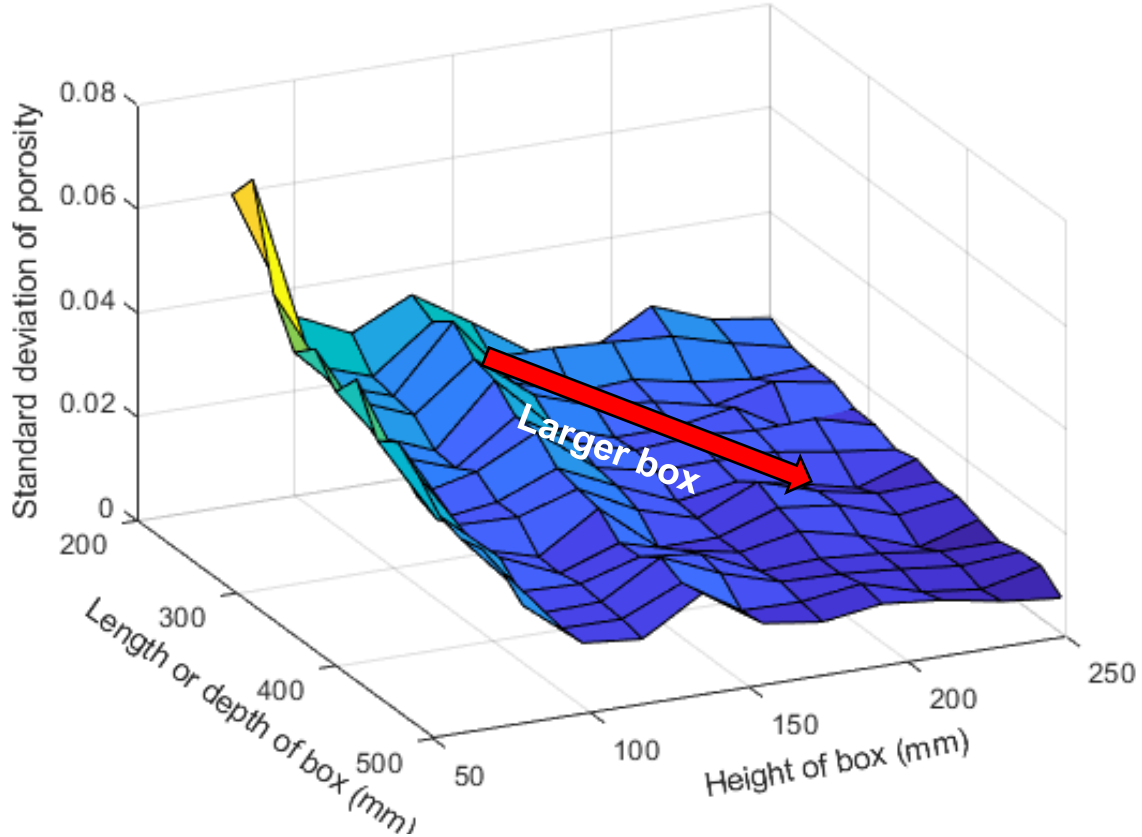
Prediction of porosity from model: Average results





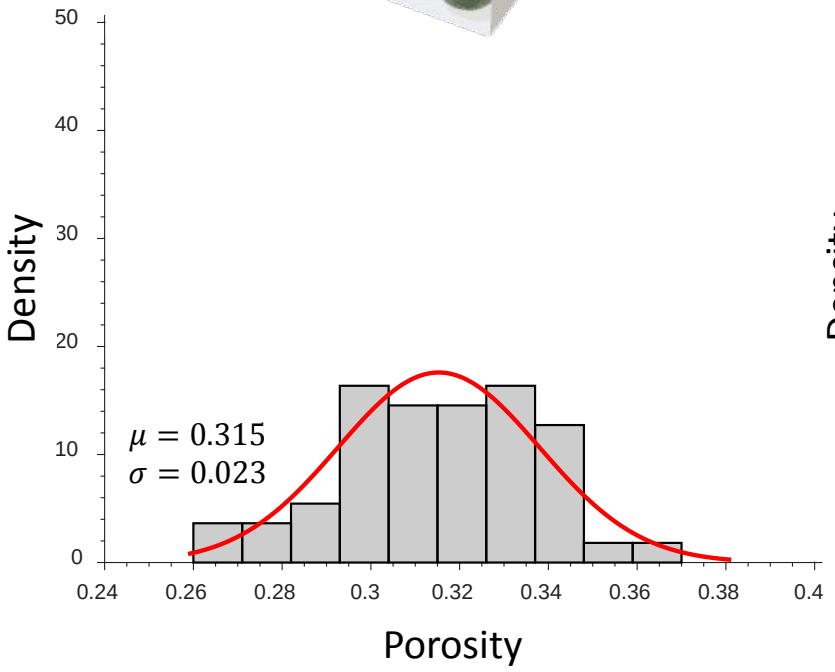
Prediction of porosity from model: Variability



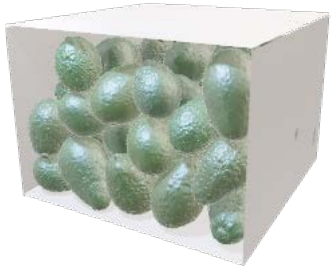


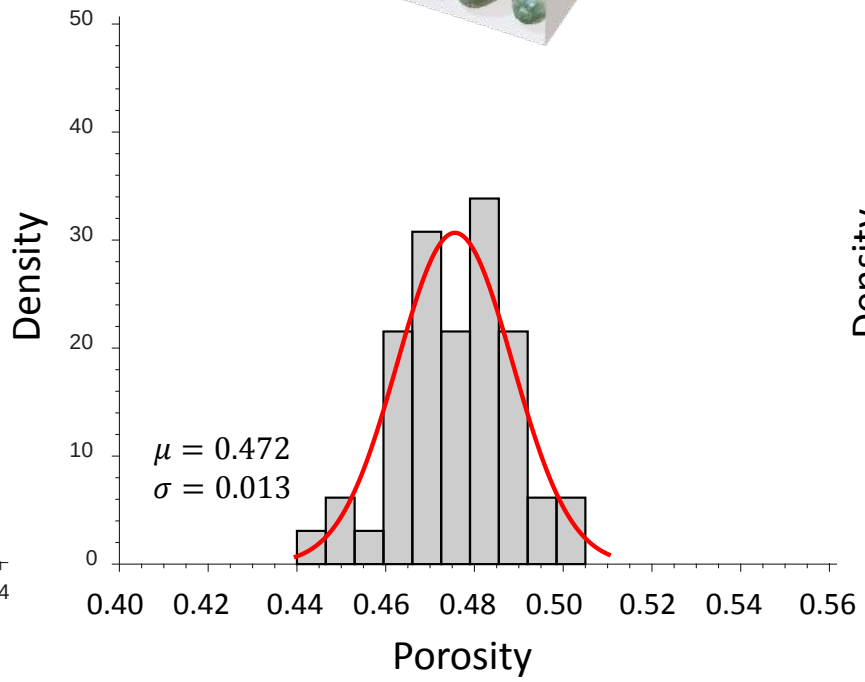
Prediction of porosity from model: Porosity distribution

263 x 263 x 118 mm

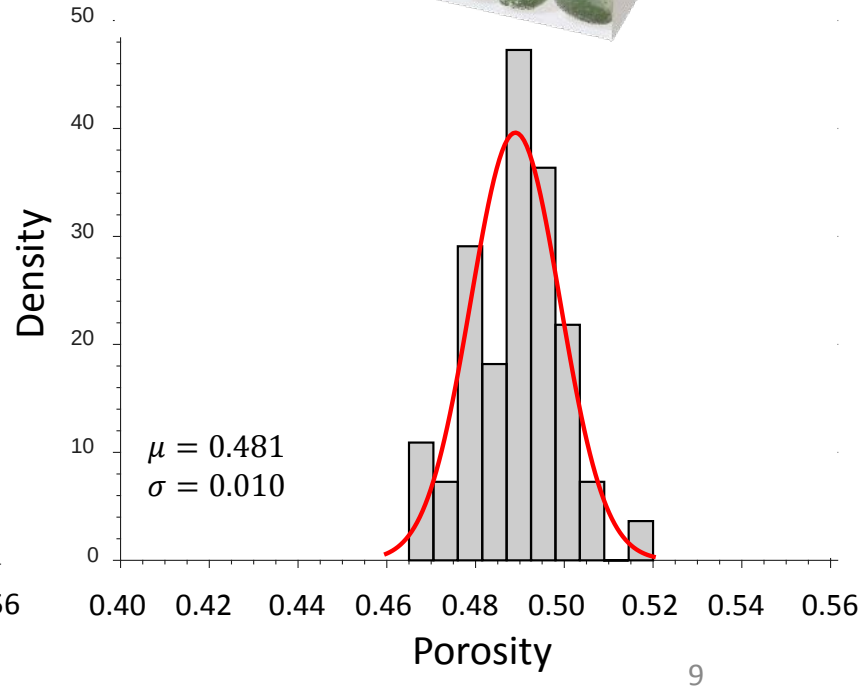


347 x 347 x 250 mm





473 x 473 x 250 mm



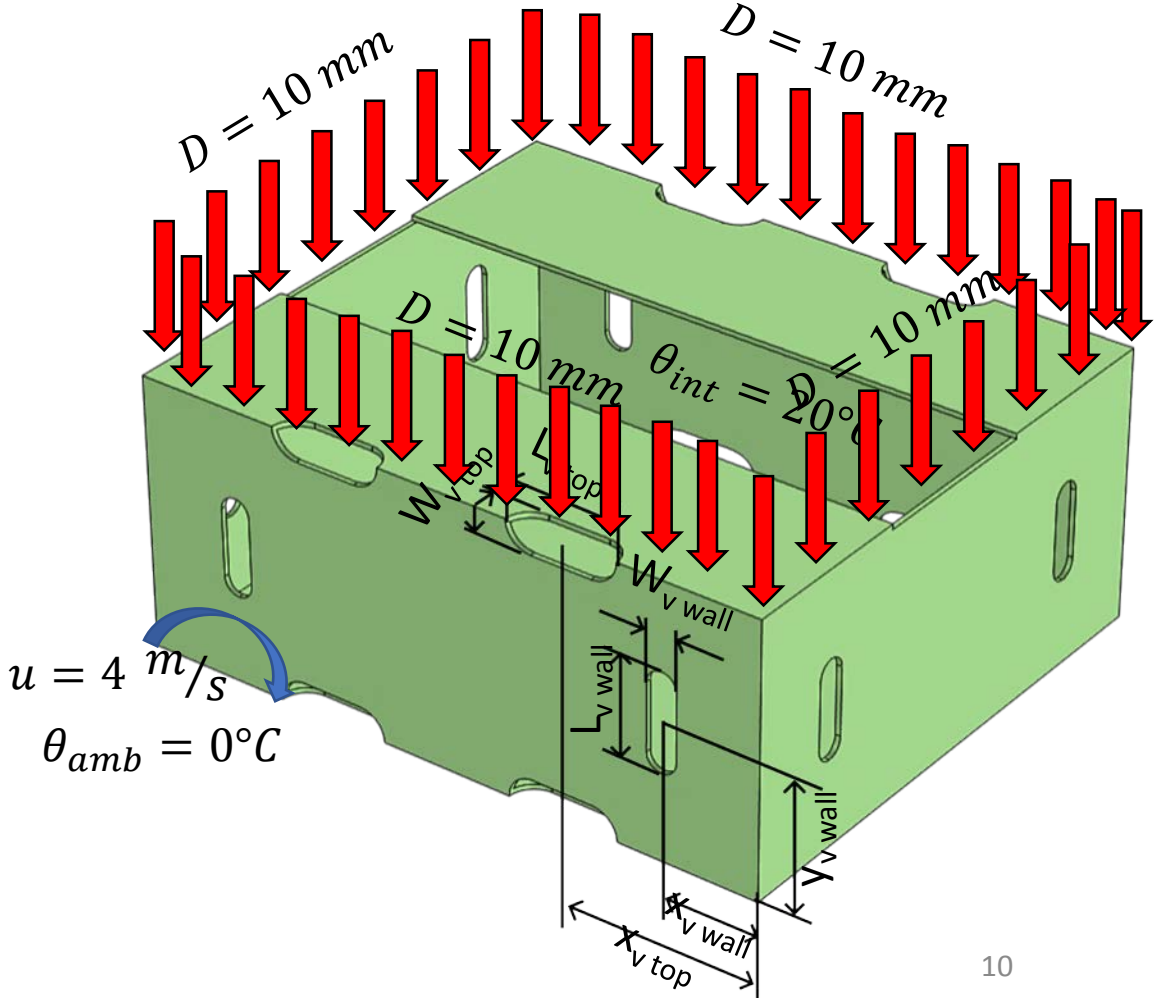
Case study: Bulk packed avocado box model-based design

- Optimisation of 11 kg avocado box (429 x 361 x 180 mm)
- Individual boxes are chilled down (initial temperature = 20°C) with forced cooling (4 m/s air at 0°C)
- Cooling and mechanical strengths were modelled
- Equivalent properties based on packed avocado porosity of box interior were used

FUNCTIONALITIES TO BE OPTIMISED:

Cooling performance:
Minimise cooling time

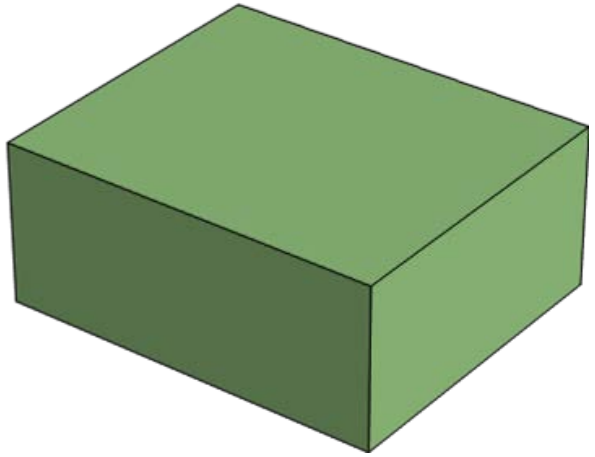
Mechanical strength
Maximise strength



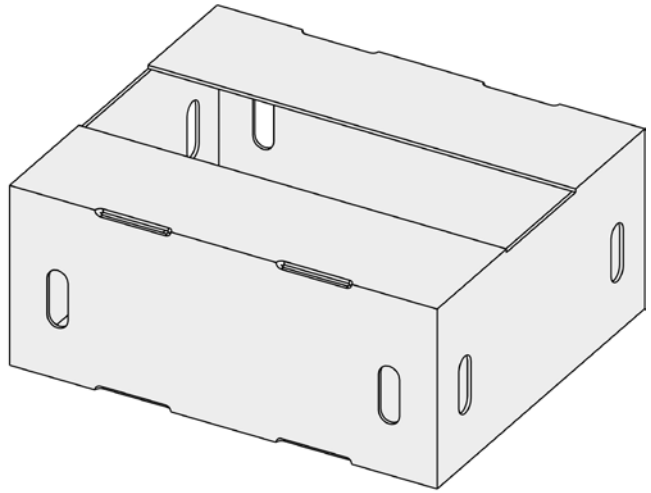
Optimisation process

Real avocado packing geometry → Equivalent avocado packing properties → Case study: Box optimisation (Genetic algorithms)*

- Porosity
- Mass
- Number of avocados



- Heat transfer properties as a function of porosity

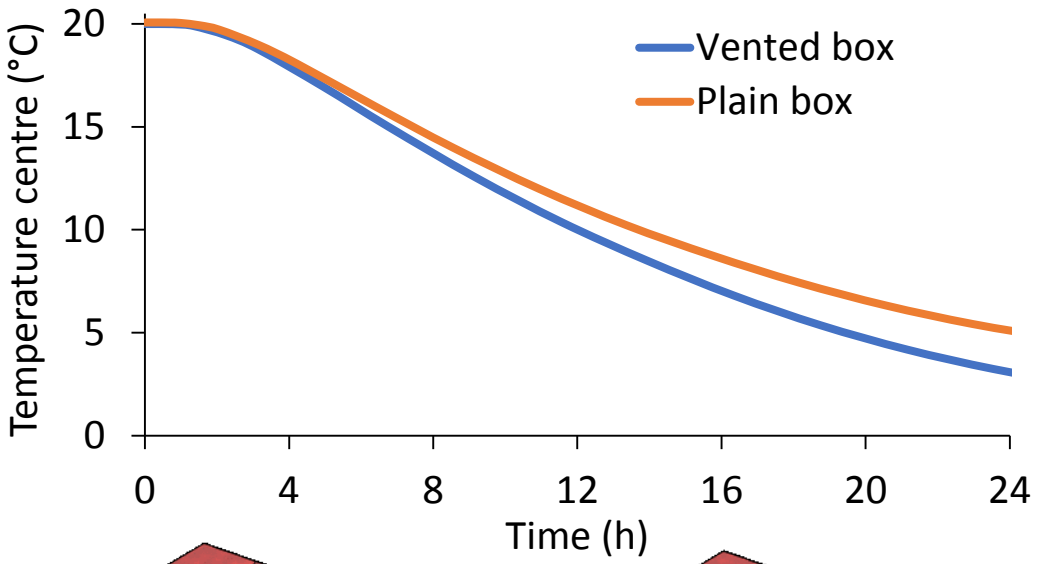


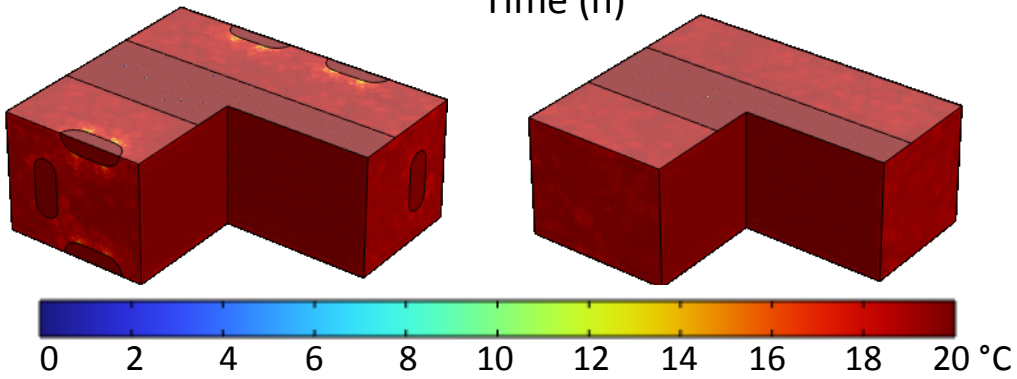
- Cooling performance
- Mechanical strength

*Martinez-Hermosilla, G. A., Kueh, C., Dahm, K., & Bronlund, J. E. (2018). Combined modelling methodology for optimisation of box design based on hybrid genetic algorithm. *Packaging Technology and Science*, *31*(11), 709-722.

Preliminary results: Individual funtionalities

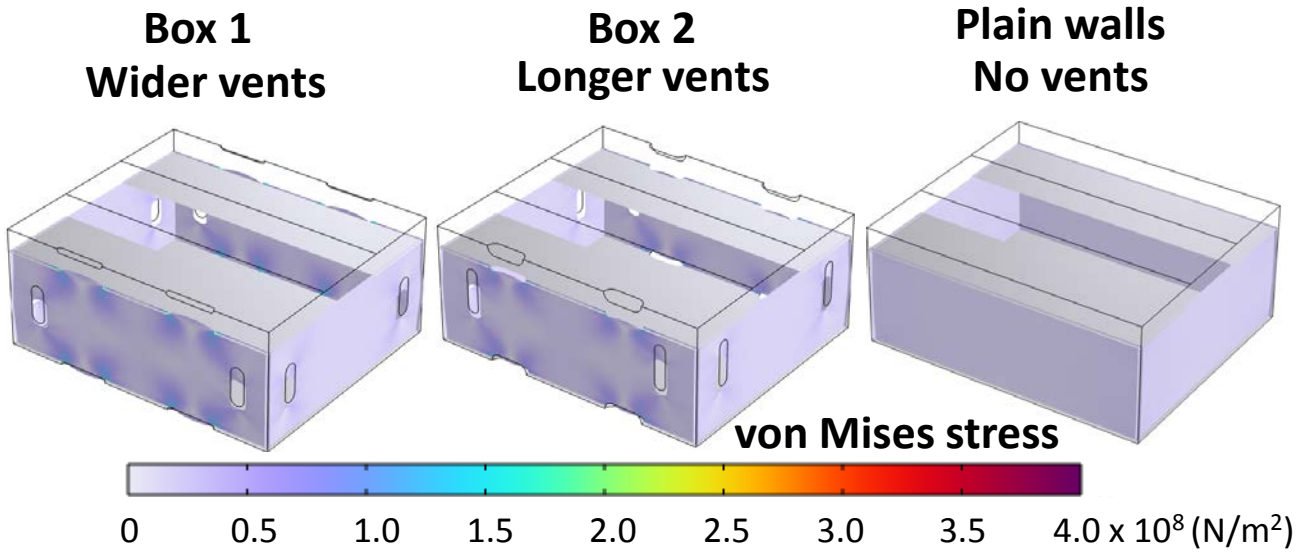
Cooling performance



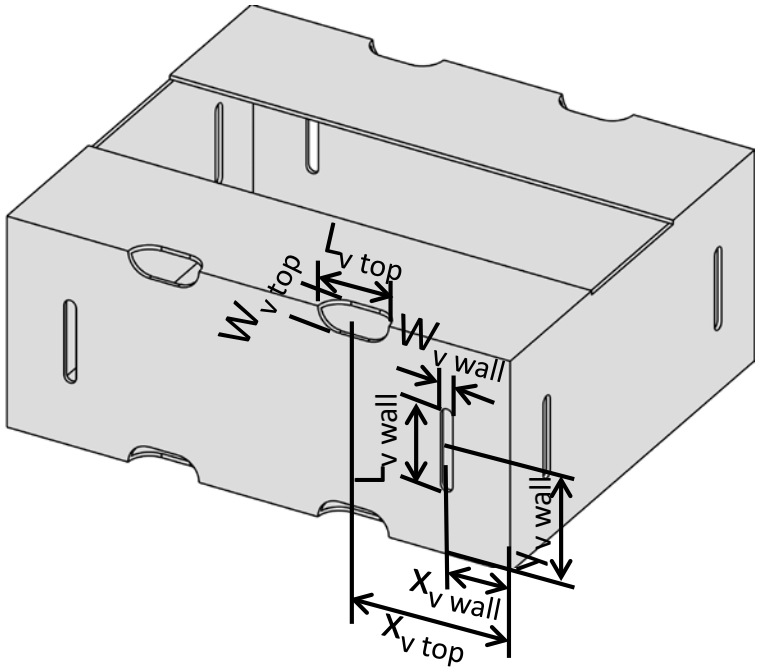


Mechanical strength performance

	Norm reaction force
Box 1	64.9 %
Box 2	80.8 %



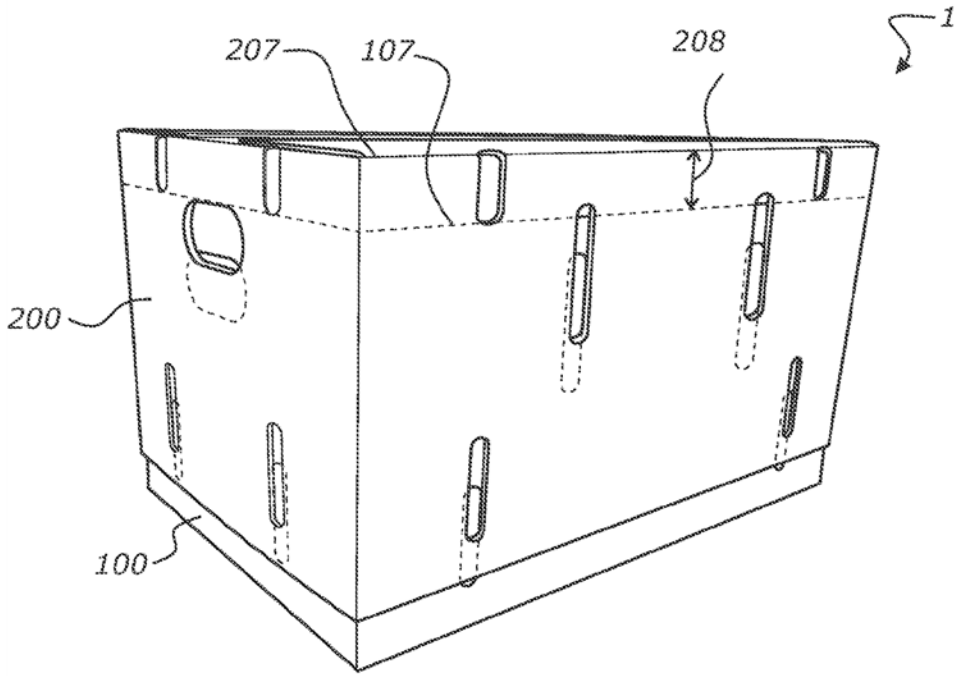
Preliminary results: Optimum result



Dimension	
L_{vtop}	60.54 mm
W_{vtop}	18.06 mm
x_{vtop}	103.35 mm
L_{vwall}	80.96 mm
W_{vwall}	10.41 mm
y_{vwall}	48.80 mm
x_{vwall}	-1.53 mm

Functionally	
Norm reaction force	82.4%
Cooling performance	6.43 °C (box centre after 24 h)

An existing packaging design based on this methodology



- Optimisation of telescopic box for apple export
- Optimum design for different count sizes
- Study conducted from theory to manufacture of a commercial packaging
- 33% faster and even cooling performance compared to the previous design
- Increase in 54% of vented area with no reduction of mechanical strength

PATENTS:

Martinez, G., East, A., & G. Lenting (2021). Vented Produce Pack. New Zealand Patent 780567

Martinez, G., East, A., & G. Lenting (2022). Empaque tipo contenedor con tapa, conformado por dos cuerpos, una tapa y un contenedor, que juntos conforman el empaque…. Chilean Patent 10542

Other potential applications

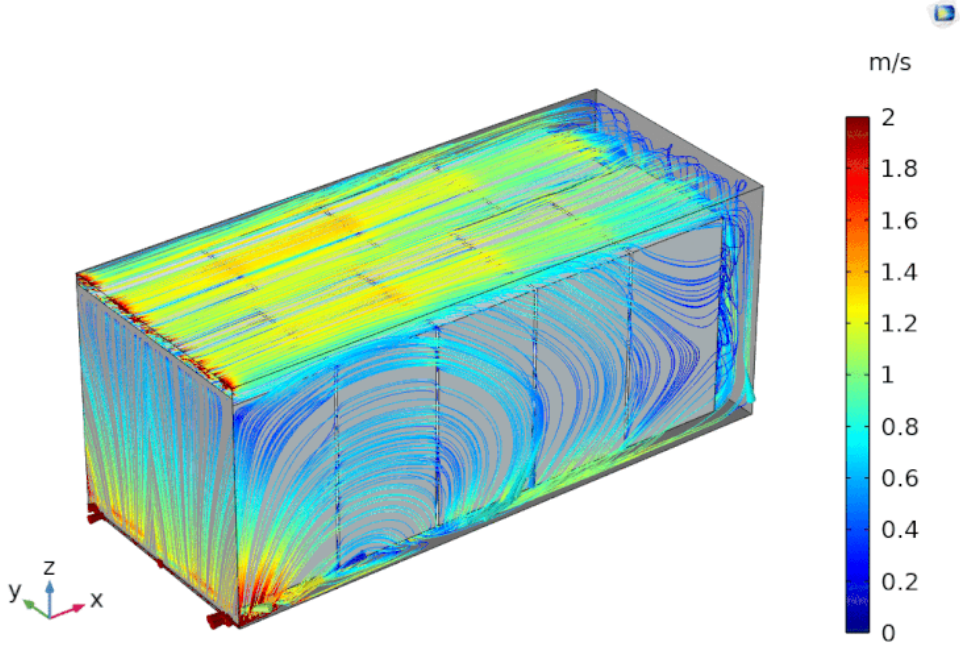
Avocado bin filling studies

www.thegoodavocado.com.au

Modified atmosphere packaging

www.packagingnew.co.uk

Thank you very much for your attention
Muchas gracias por su atención



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How to calculate and combine functionalities?

What functionalities are considered?

How to calculate each functionality?

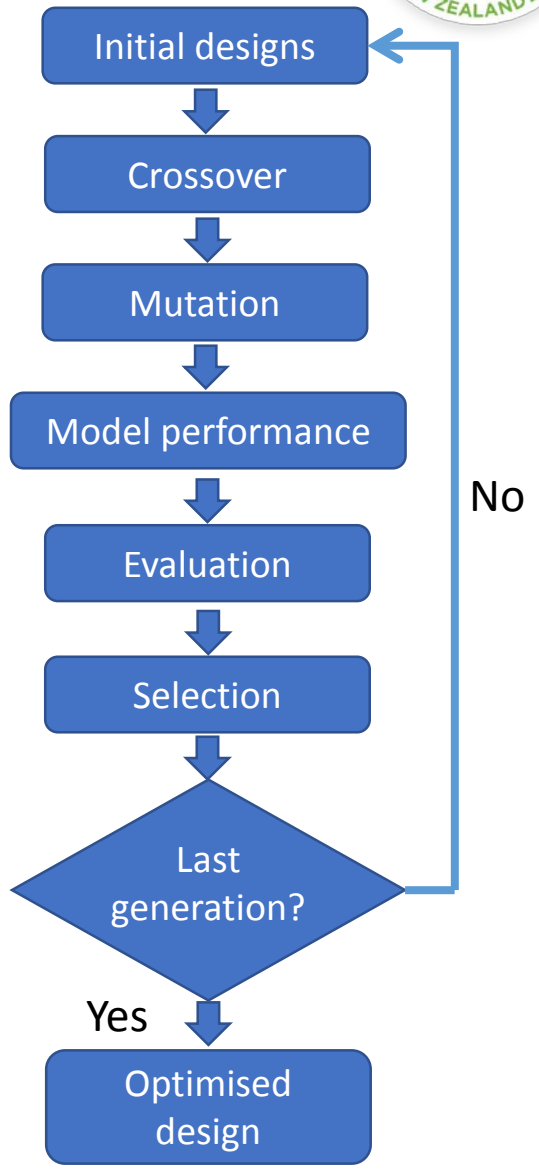
How to combine the functionalities?

Modelling

Mathematical modelling and simulations

Genetic algorithm*

Weighted combination



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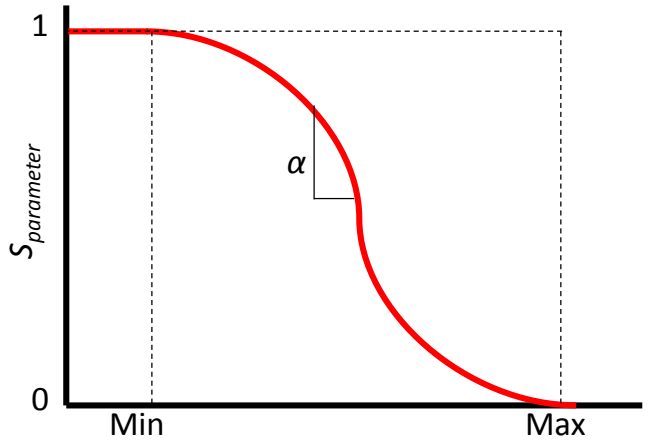
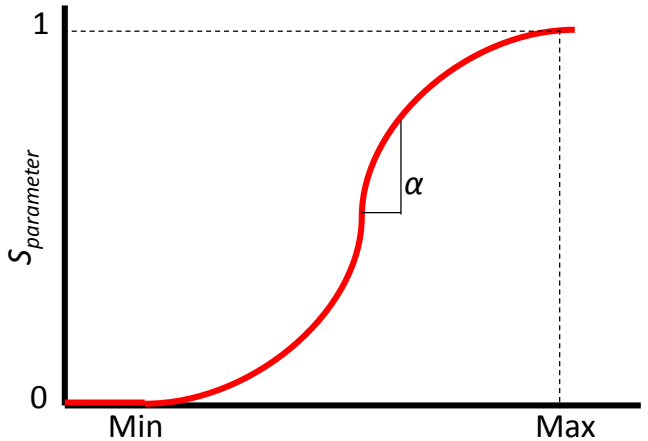
Functionality evaluation



Cooling time
Total cardboard area per box

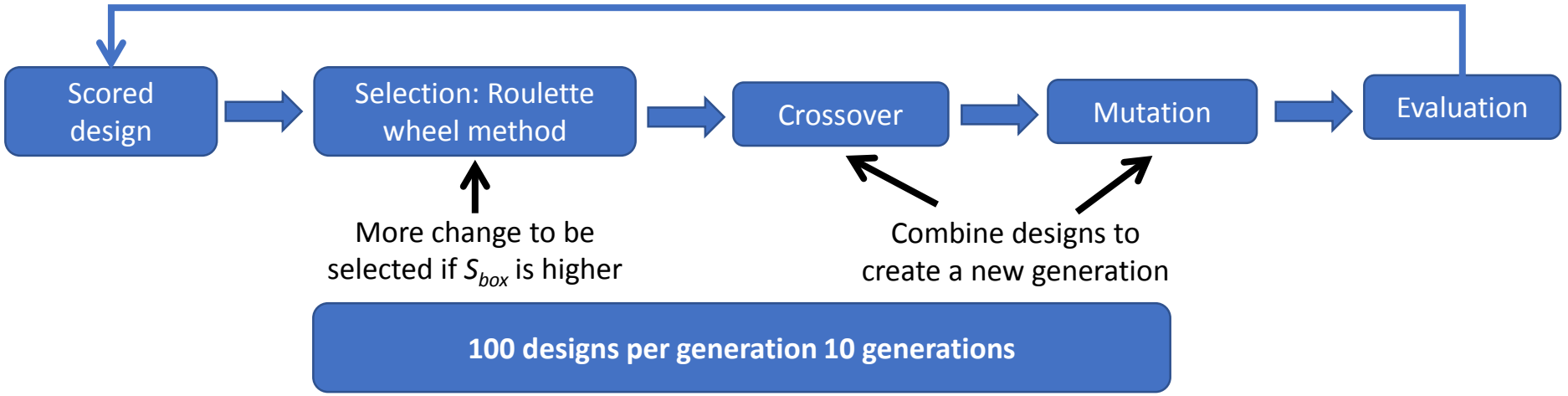


Number of boxes per pallet
Number of boxes per ULD

$$S_{parameter} = f(Min, Max, \alpha)$$

$$S_{box} = \sum_{i=1}^{n} S_{parameter_i} \cdot W_{parameter_i}$$

$$\sum_{i=1}^{n} W_{parameter_i} = 1$$



Loose fill boxes for avocado export

https://theavoclub.com.au/product/the-avo-addict-10kg-box/

Journey from New Zealand to different destinations

Destination	Tauranga
Singapore	17
Port Kelang (Malaysia)	15
Hong Kong	14
Keelung (Taiwan)	16
Shanghai (China)	18
Ningbo (China)	20

*OOCL (2017). Product and Service Guide: Australia/New Zealand

- Boxes filled with about 11 kg of avocados
- Random avocado placing
- Diverse shapes and sizes

PACKAGING DESIGN IS CRUCIAL

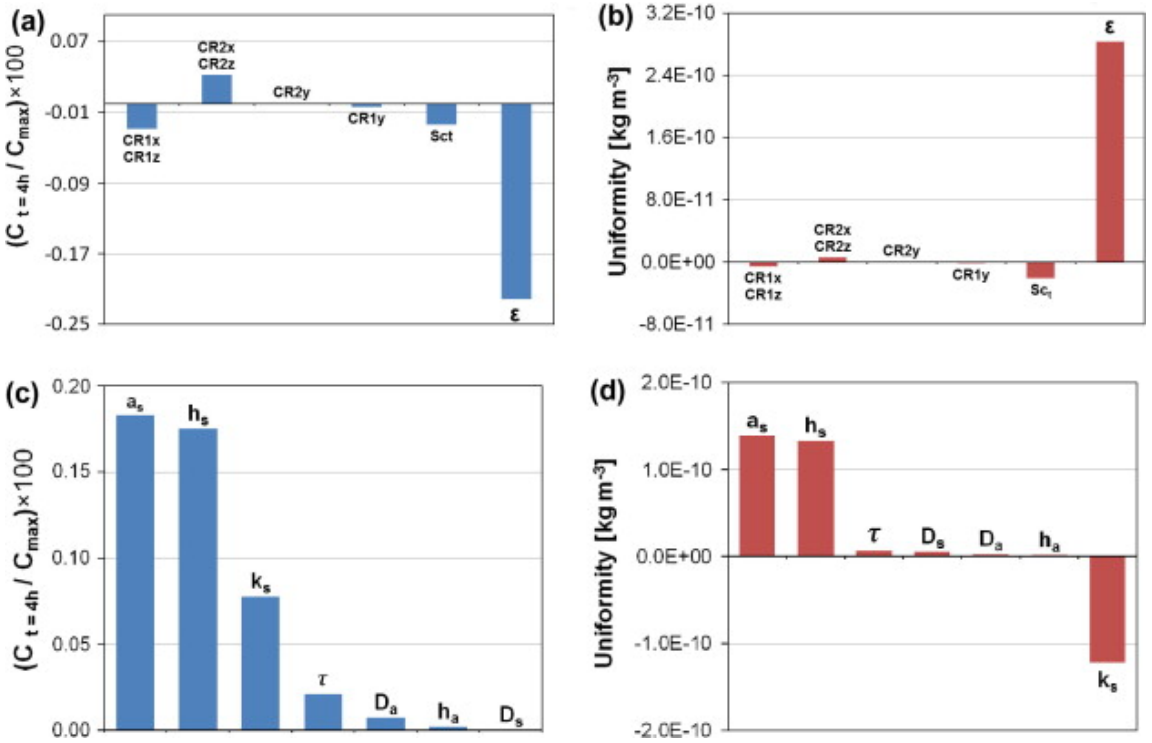
- Helps with logistics
- Keeps adequate conditions
- Branding

Porosity and fruit geometry

https://theavoclub.com.au/product/the-avo-addict-10kg-box/

$$Porosity = \frac{\sum_{i=1}^{n} Volume\ of\ fruit_i}{Volume\ of\ box}$$

Effect of porosity on gas concentration between packed apples*



*Ambaw, A., et al (2013). Porous medium modeling and parameter sensitivity analysis of 1-MCP distribution in boxes with apple fruit. *Journal of Food Engineering*, *119*(1), 13-21.