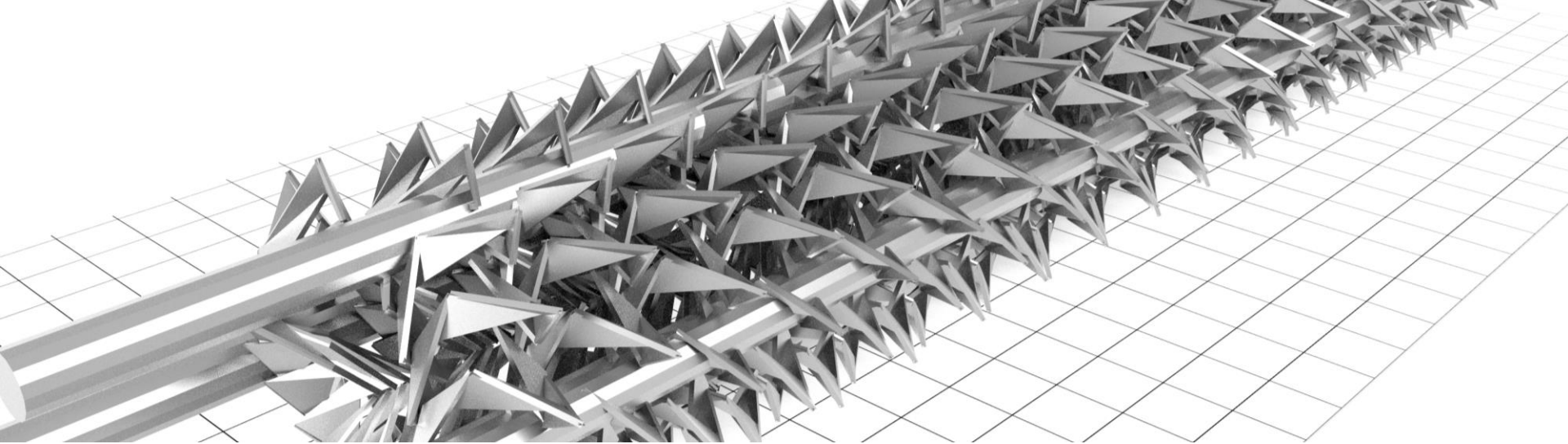


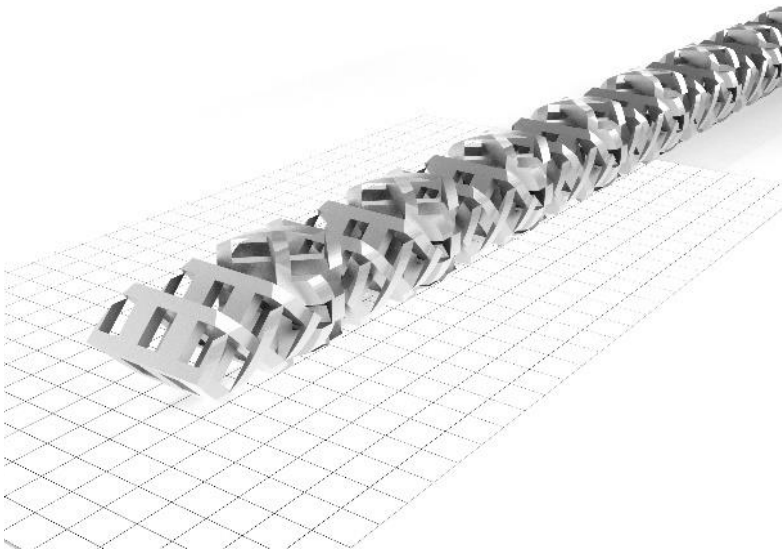
Automated and Robust Evolution-based Design Process of Static Mixer with Large Geometric Variation

Part of AI4Design Research Portfolio in CSIRO

Paulus Lahur | 31 October 2024
with Gerald G. Pereira, David Howard, Michael Breedon, Phil Kilby, and Christian H. Hornung
Australia's National Science Agency

Introduction

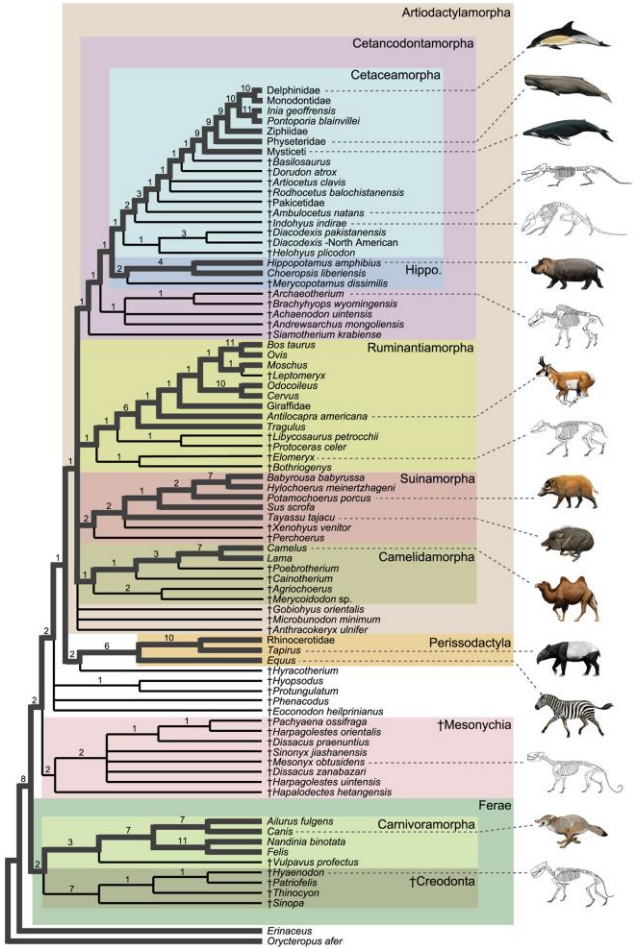
- What is a static mixer?
  - A device that mixes fluid without any moving part. Fluid gets mixed simply by flowing through a tube containing the device ➔
  - Wide applications: mixes multiple fluids, extracts material from solutions, etc.
- We already have static mixer designed by domain expert.
- The challenge: design a better static mixer for removing specific ion (in this case: copper ion) from a solution.



Intriguing Question

Can we produce better geometries by mimicking the way Nature evolves living organisms in response to certain environment?

- Very long process from DNA ➔ protein ➔ cells ➔ tissues
- Just use the basic concept: geometric parameters ➔ geometry
- Genetic Algorithm (GA) is part of Artificial Intelligence (AI)
- Contrast to Machine Learning (ML) no training

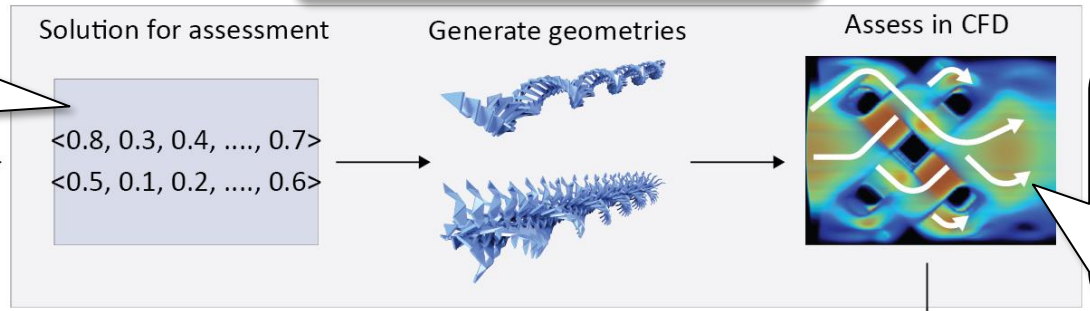


Courtesy of Michelle Spaulding, Maureen A. O'Leary, John Gatesy - Spaulding M, O'Leary MA, Gatesy J (2009) Relationships of Cetacea (Artiodactyla) Among Mammals: Increased Taxon Sampling Alters Interpretations of Key Fossils and Character Evolution. PLoS ONE 4(9): e7062. doi:10.1371/journal.pone.0007062

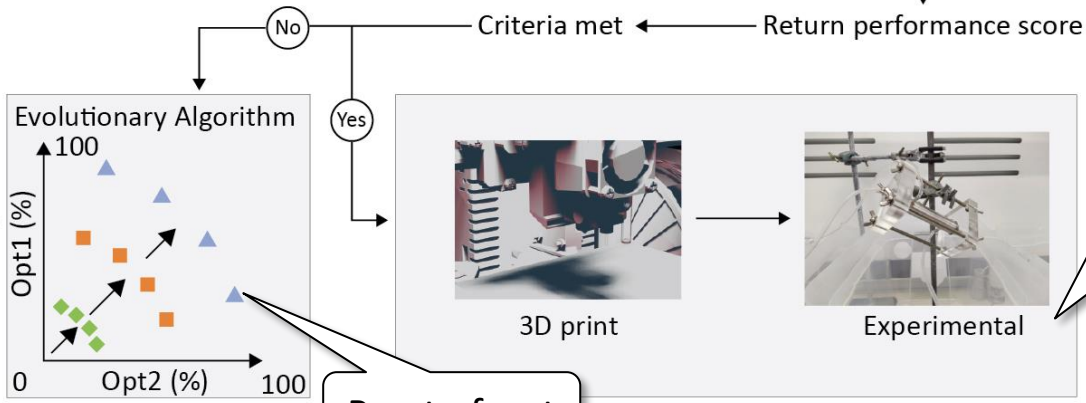
Evolution System: Automated & Robust

Genetic information: geometric parameters

Large geometric variation



Lattice-Boltzmann method: Robust. CFD is computationally intensive!

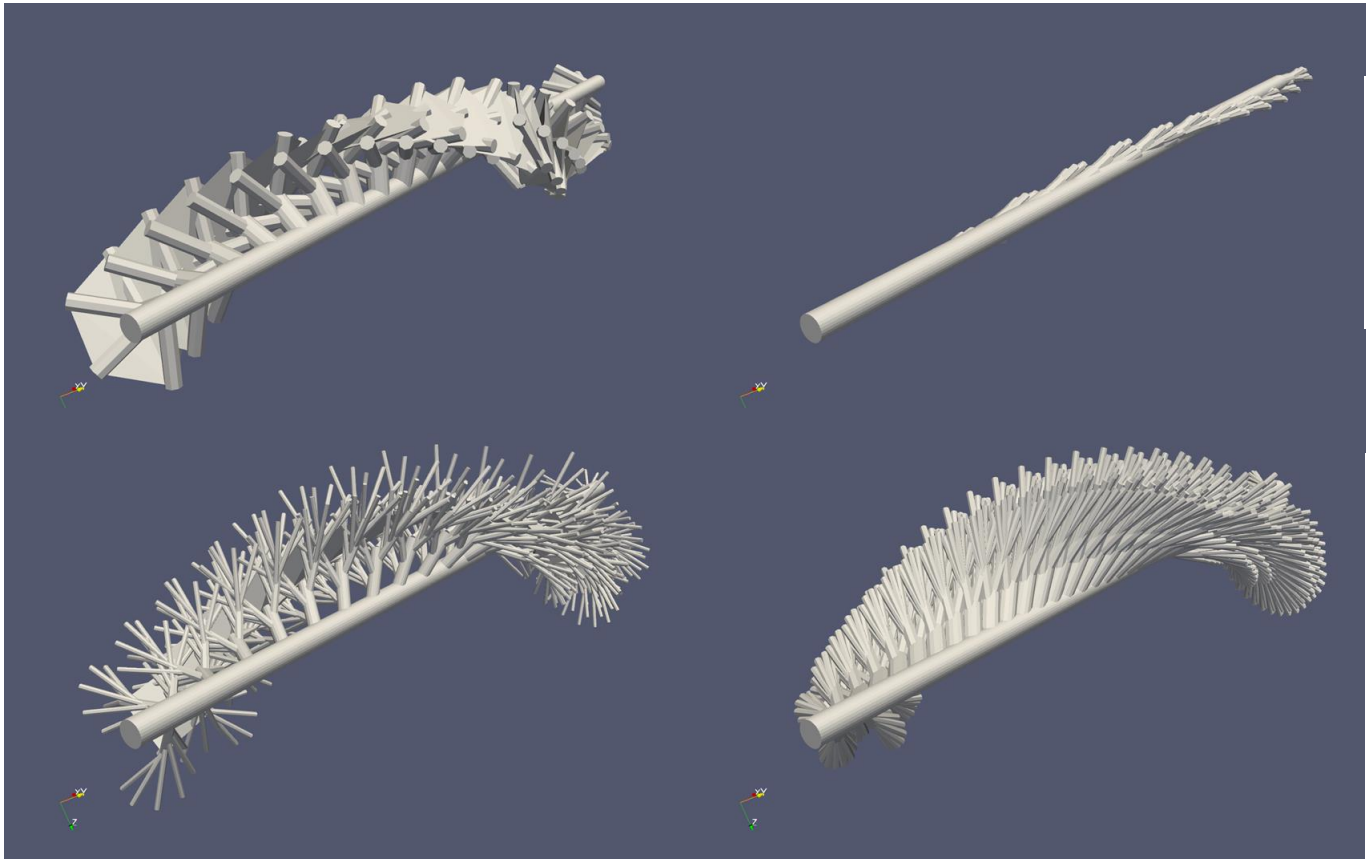


Verify champions using experiments ➔ labour intensive

Pareto front

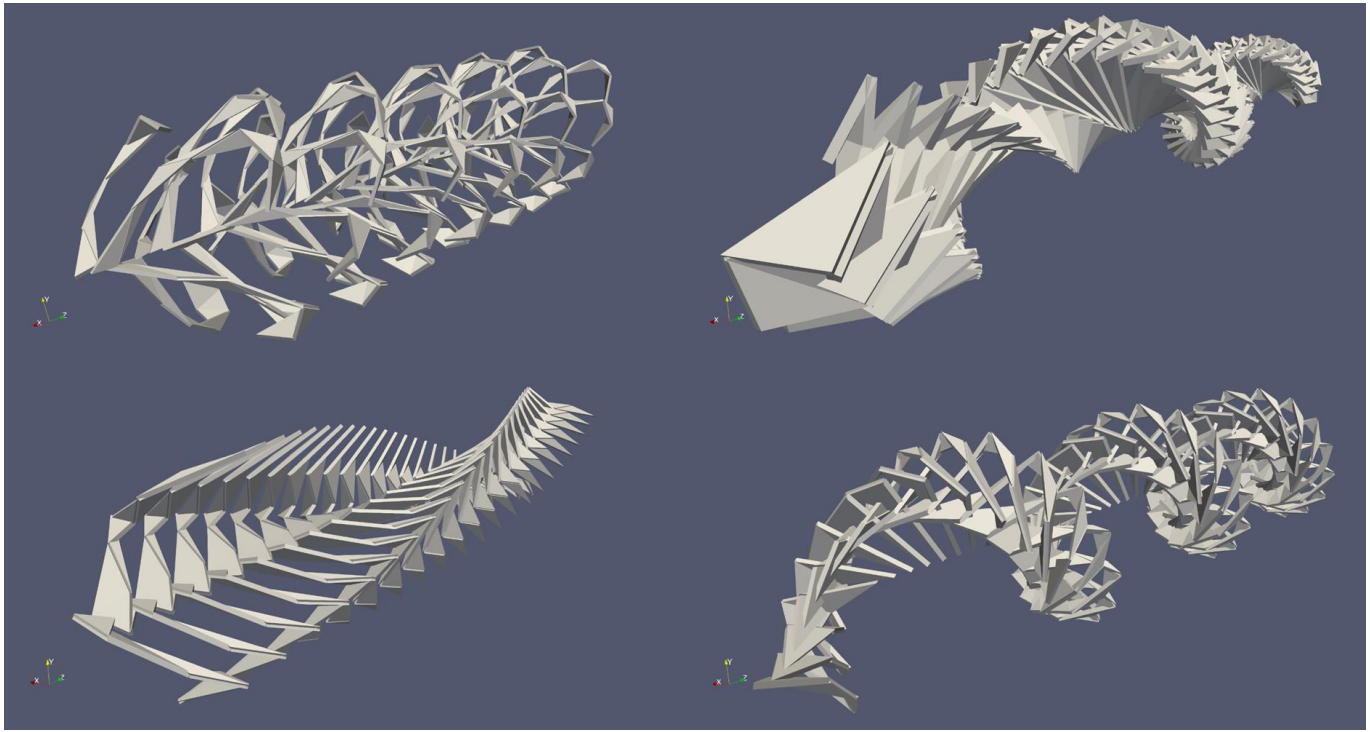
Genetic Algorithm:
- Population
- Crossover
- Mutation
- Fitness
- Selection

Geometry Generation: Tree-based



- Recursive ➔ branch.
- 10 parameters ➔ compact design space ➔ faster to explore.

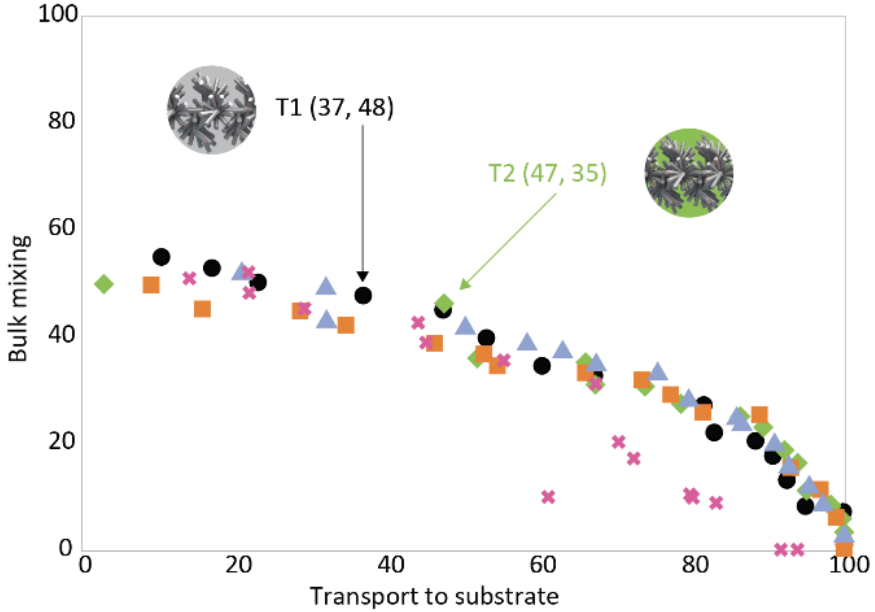
Geometry Generation: Ribbon-based



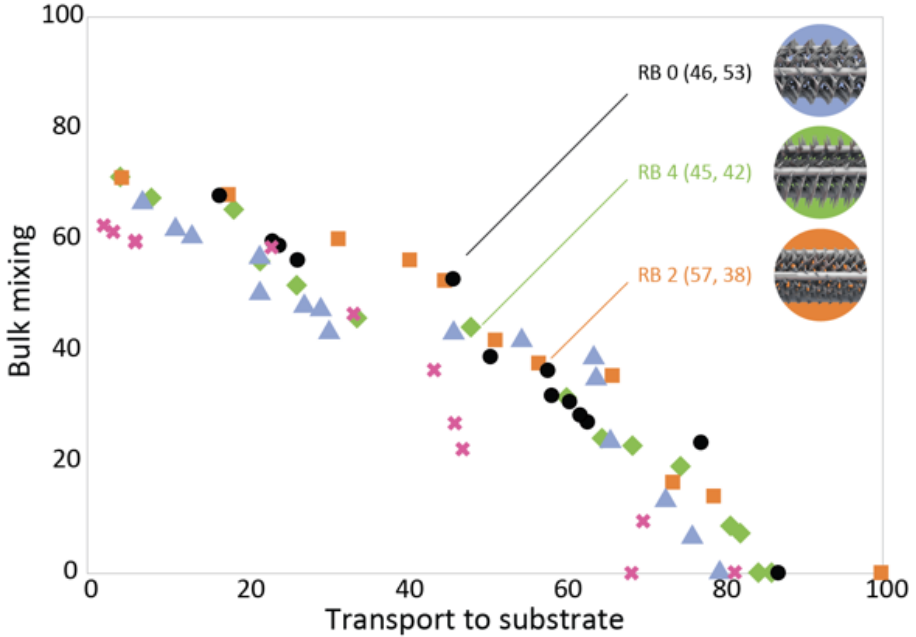
- Non recursive.
- 30 parameters ➔ large design space ➔ slower to explore.

Results of Computations

Typical computation: 150 generations, 16 individual in population



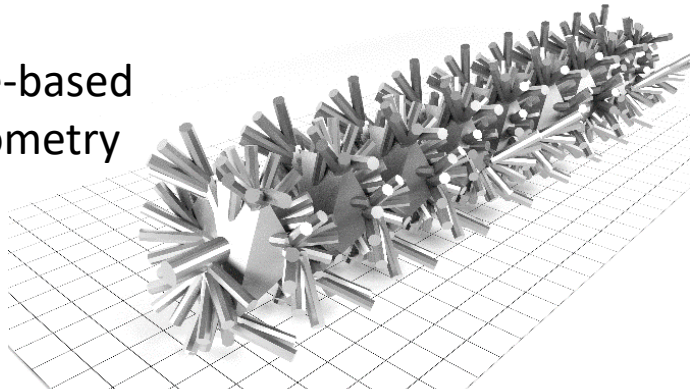
Tree-based geometry

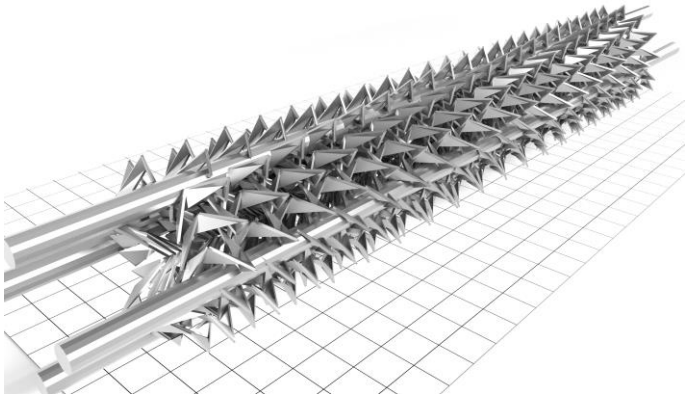


Ribbon-based geometry

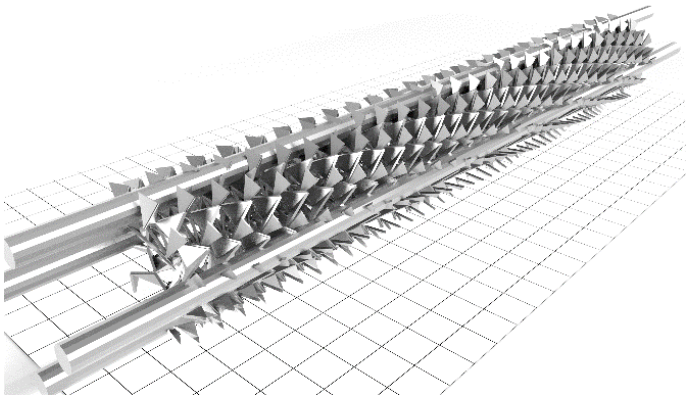
Champion Mixers

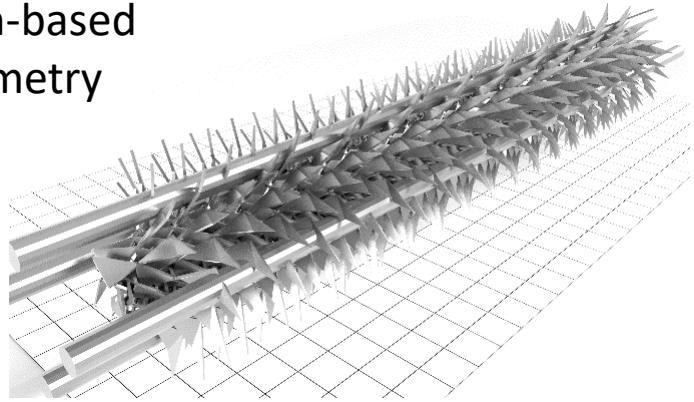
Tree-based geometry





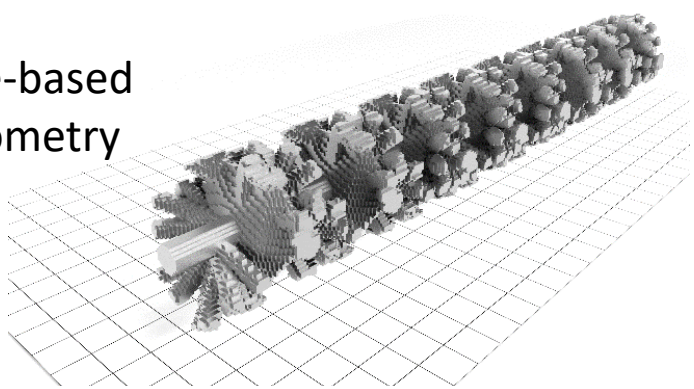
Ribbon-based geometry

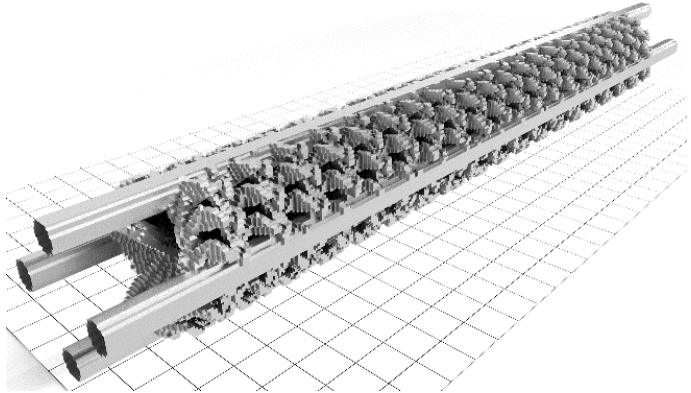




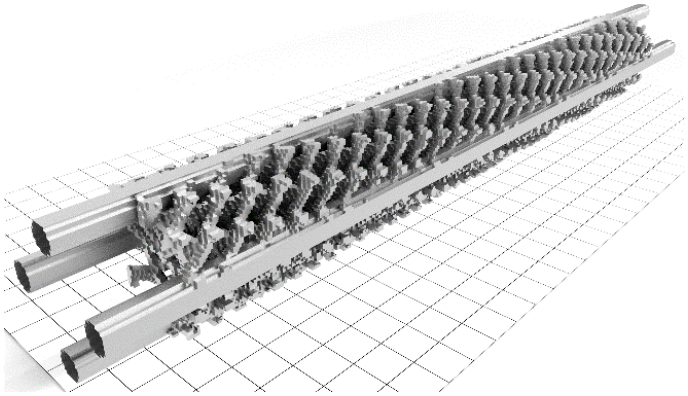
Champion Mixers as Seen by CFD & 3D Printer

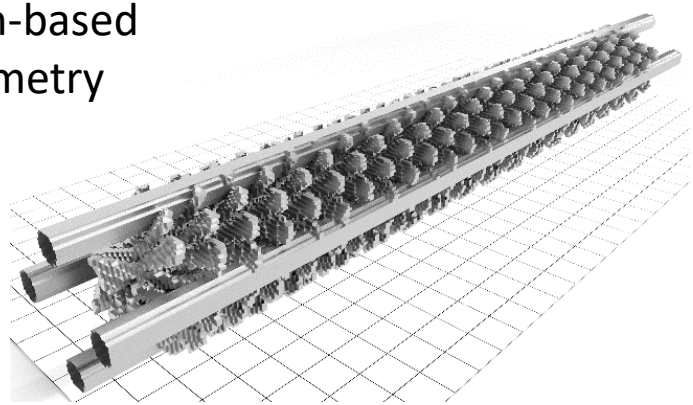
Tree-based geometry





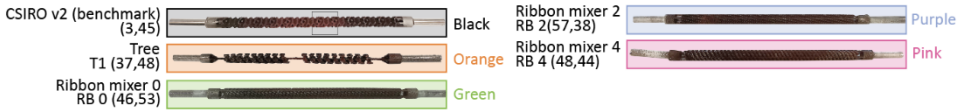
Ribbon-based geometry

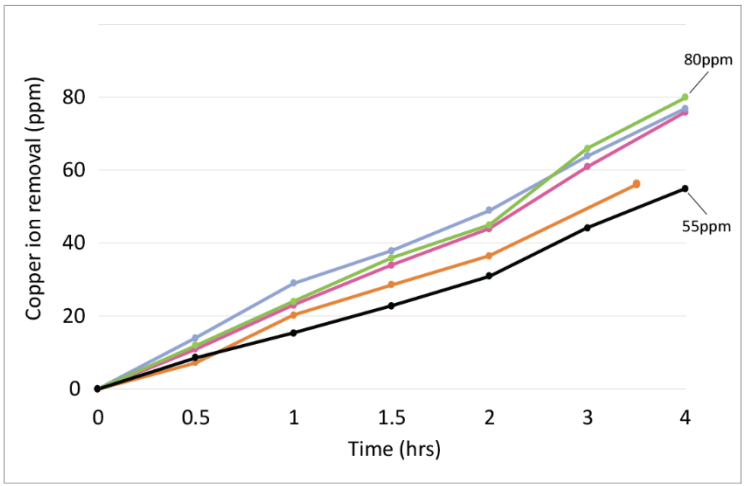




Experimental Verification

Remove copper ion from solution ➔ more is better





Tree-based geometry is better than benchmark

Ribbon-based geometries perform the best ➔ 45% better than benchmark

Current State

- Journal
  - Freeform Generative Design of Complex Functional Structures, Gerald G. Pereira, David Howard, Paulus Lahur, Michael Breedon, Phil Kilby, and Christian H. Hornung, Scientific Reports, 14, 11918, (2024)
- Three patents
- Project expansion
  - More projects on various applications: Carbon Capture, Hydrogenation, Fermentation, Polymerisation, Airlift, Distillation.
  - Exploring more geometry generators: Lindenmeyer system, TPMS (Triply Periodic Minimal Surface) etc.
  - Exploring Bayesian Optimisation to replace Genetic Algorithm.
  - Exploring additional component: Machine Learning.

Future

- The exploration continues …
  - Need to reduce the number of physics evaluations.
- Data management!
- Cloud?
  - Inherit the basic current layout in HPC computation ➔ interchangeable & scalable components:
    - Design parameter engine (Genetic Algorithm or Bayesian Optimisation)
    - Geometry engine (various types)
    - Physics evaluation engine (CFD, solid mechanics etc.) ➔ costly!
- Eventually becomes innovation tool

Acknowledgement

- We are immensely grateful to all collaborators in AIM FSP Static Mixer program and AI4Design research portfolio, who have helped in all aspects of the project, which includes 3D printing, experimentation, material analysis as well as computing.
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Thank you

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