Presented at:

The 37th International Manufacturing Conference will be an online conference co-hosted by Athlone Institute of Technology and CONFIRM

Loughborough University

QUEEN'S UNIVERSITY BELFAST

UNIVERSITY of York

UKRI Engineering and Physical Sciences Research Council

Re-Imagining Engineering Design

Far

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mtc Manufacturing Technology Centre

JW KANE Precision Engineering Ltd

denroy

Glen Dimplex HEATING & VENTILATION

ITI a wipro company

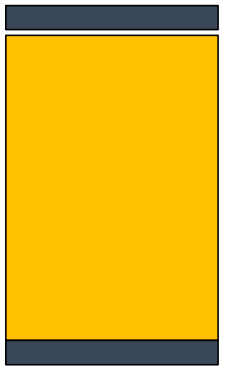
Alloyed

BOMBARDIER

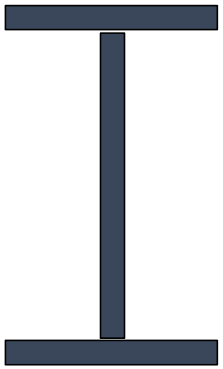
biohaviour

PROBLEM DESCRIPTION

What is physical is only the tip of the iceberg!



Wood capped with steel



Steel I-Beam

Function influences form (or form follows function)

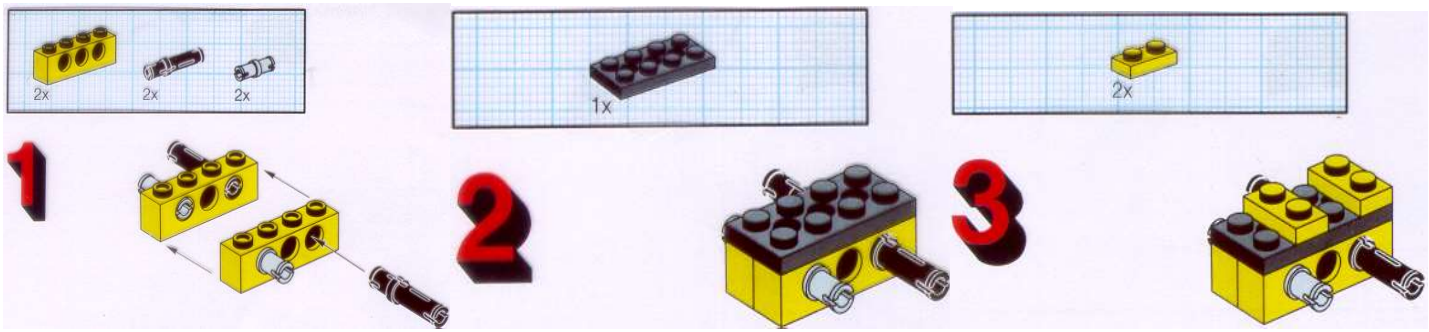
$$F(x, y, z, t, cost, material, process\ldots)$$

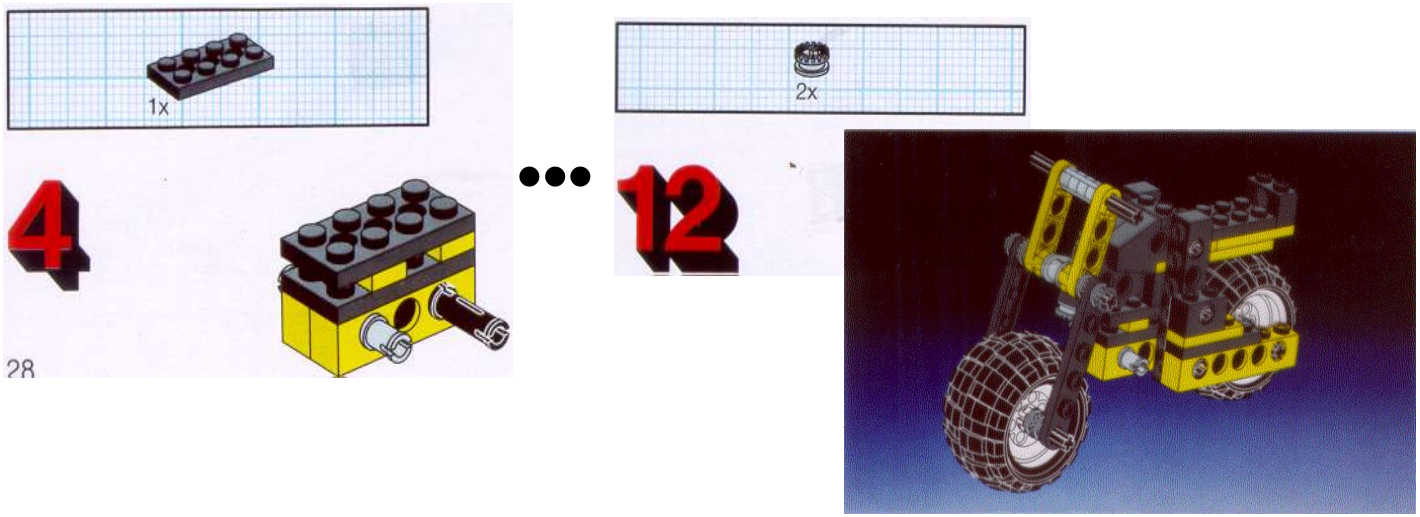
What we can see in 3D

N-dimenions

Building Complex Systems 1.- Engineer's approach

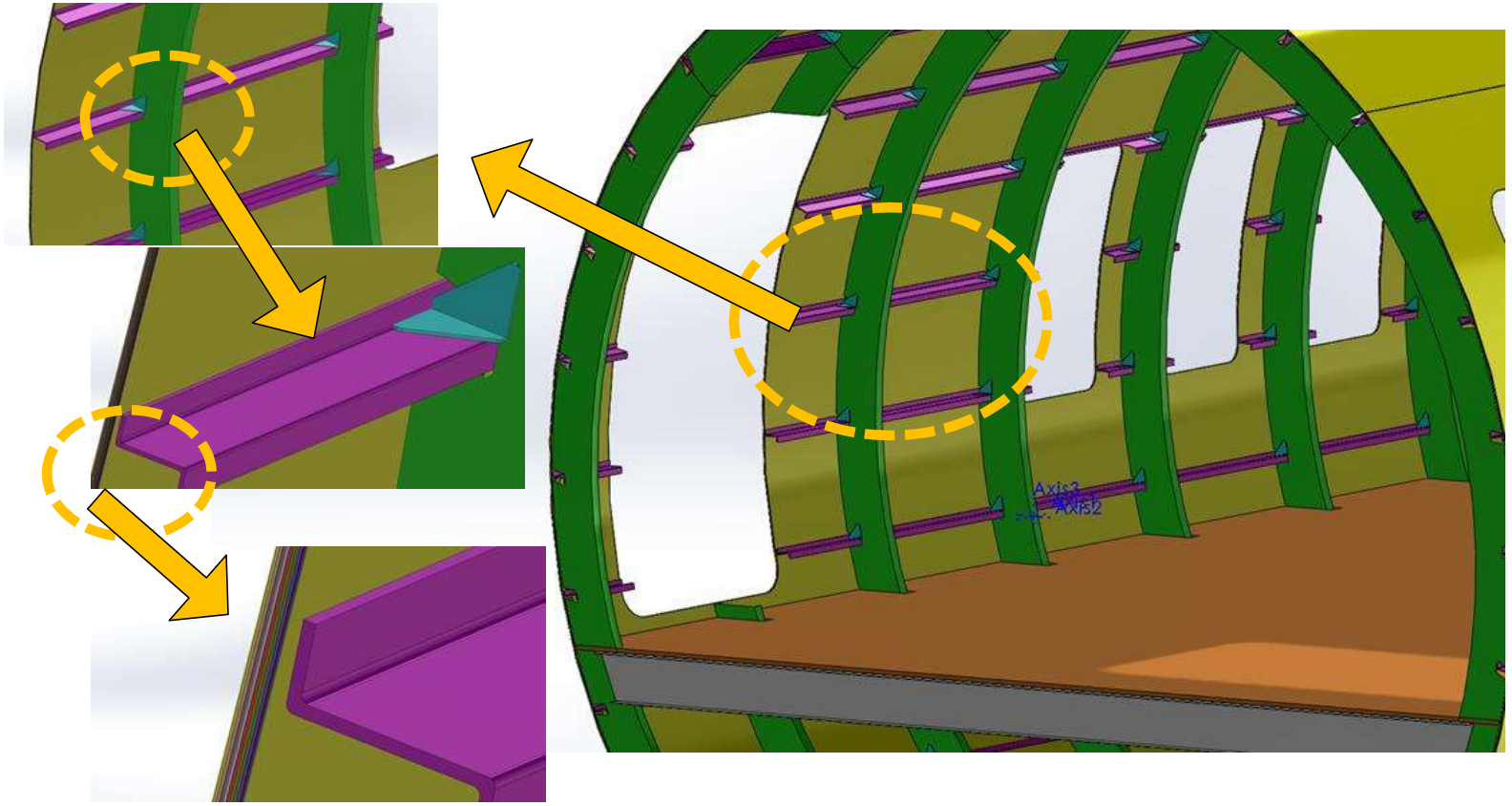
Different component designs for all of the different functions a system requires.



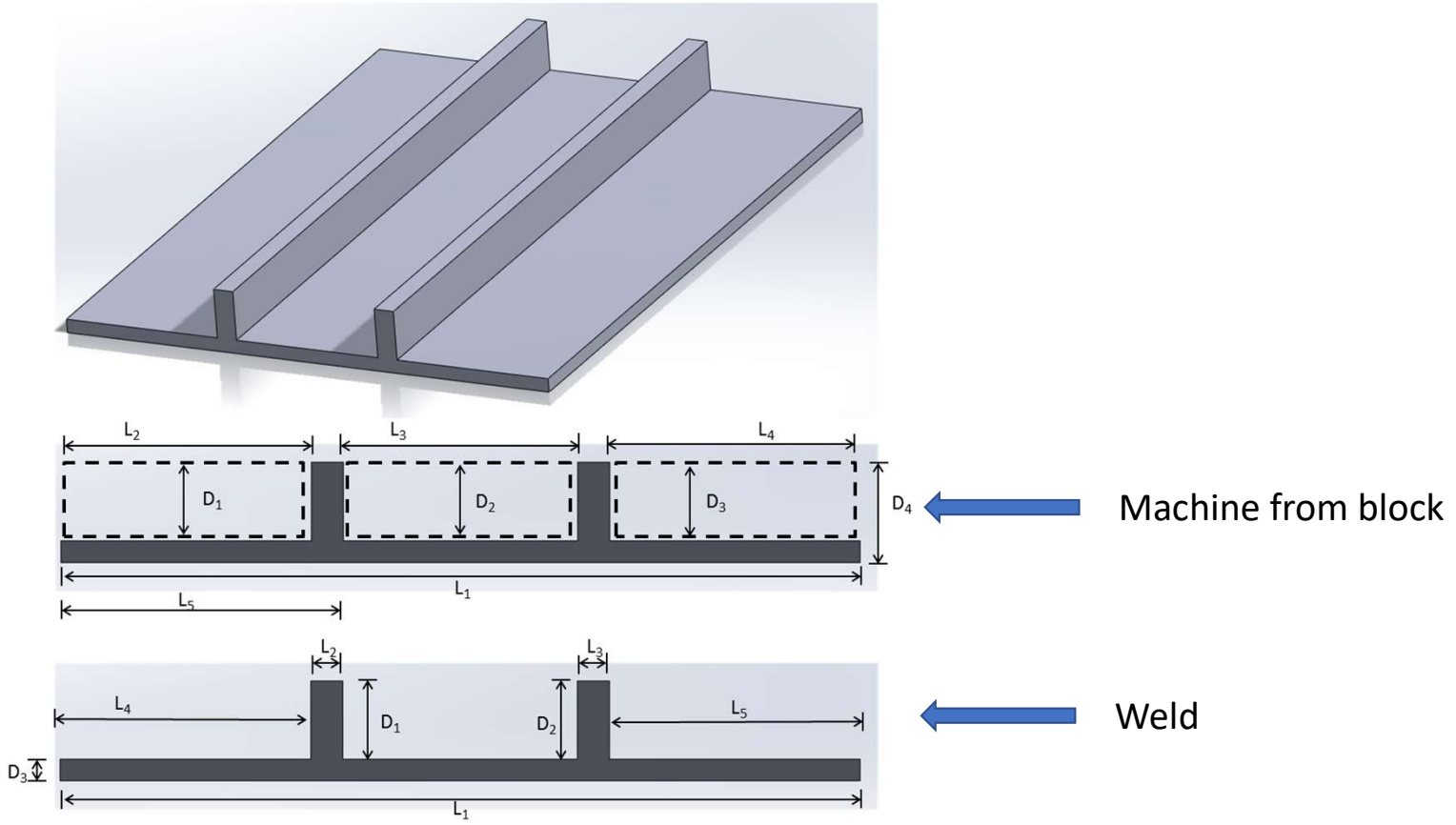


Specific parts:
One part, one job.

Manage data and understand relationships



Maintaining Design Intent



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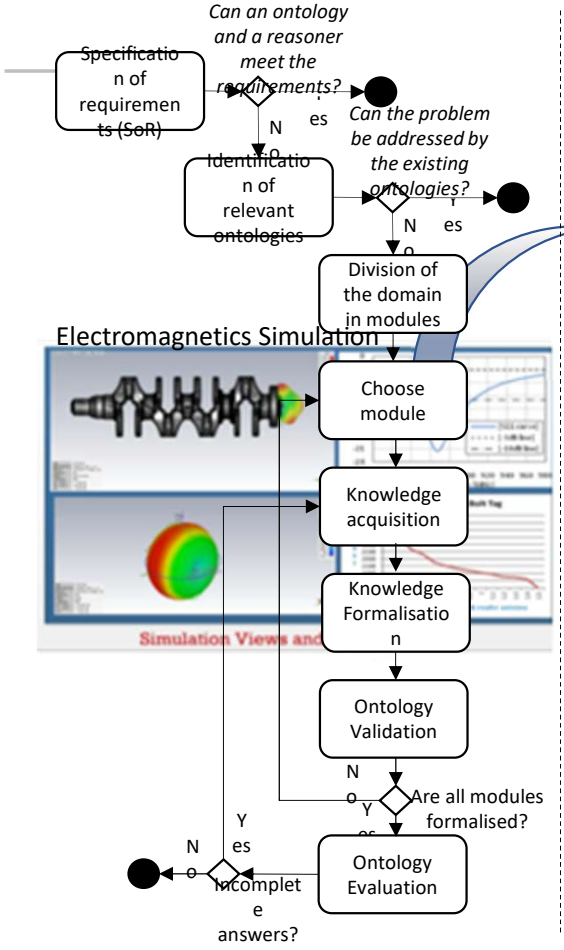
Ontology map – mind blowing!



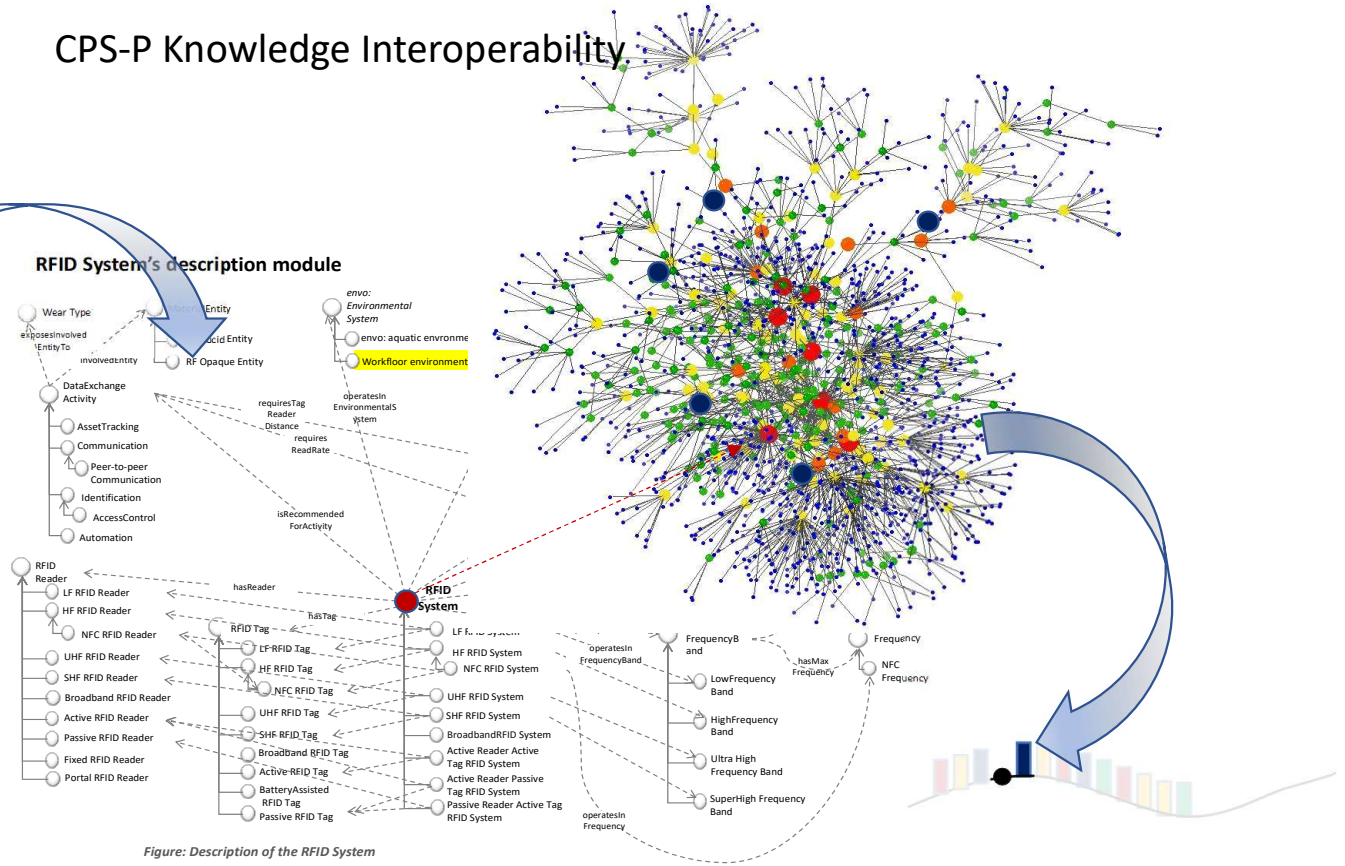
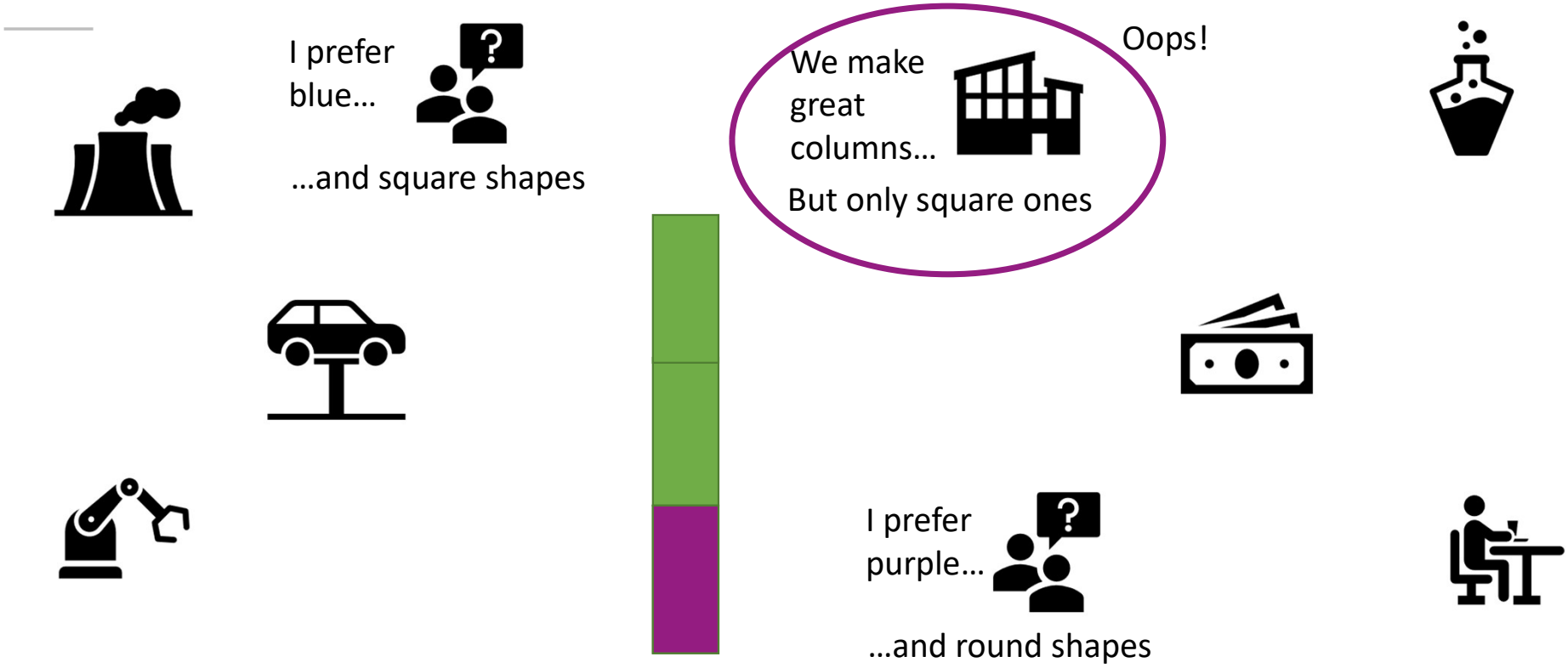


Figure: Description of the RFID System

It gets even more complicated when we think of the wider system!



Objectives are often conflicting

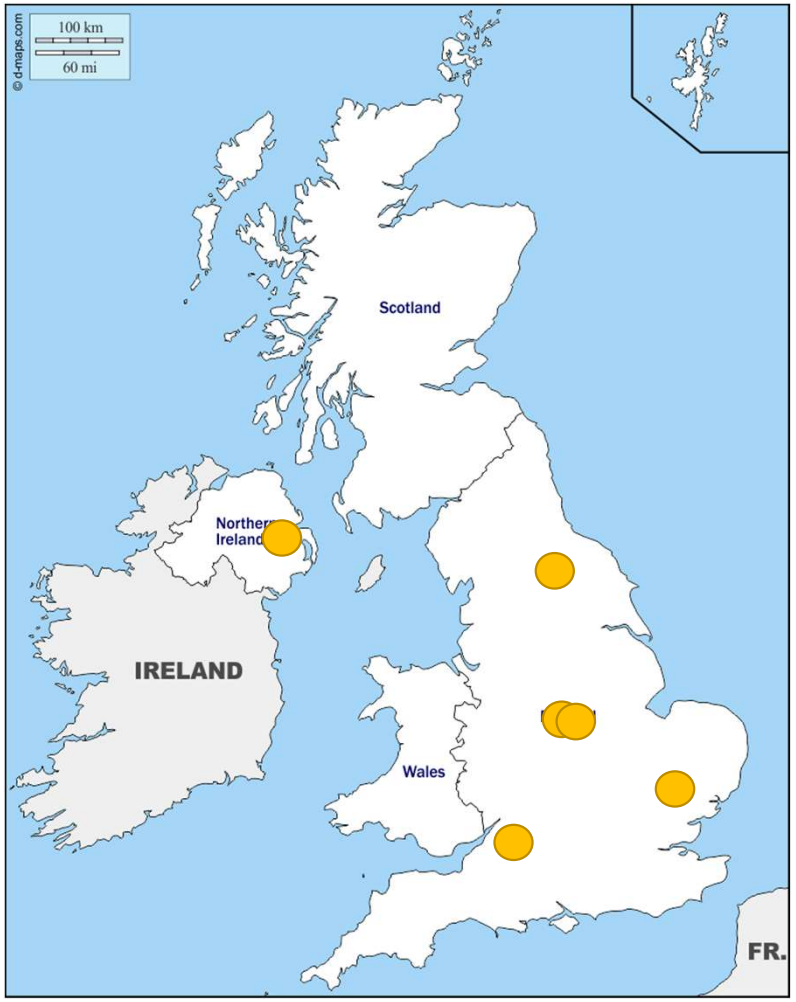
CONCEPT AND ETHOS

- Rethink design rules and processes
- Create new autonomous design processes
- Radically change roles and activities in the manufacturing organisation
- Embrace emergent behaviour for design innovation

THE TEAM

In Geographical spread…

- Partnership drawn from across UK.



In numbers…

- Total Project Value is ~£11M (Full Cost) to run for 5 years.
- 12 Academics from 3 Institutions: QUB, York, Loughborough.
- Company partners include Airbus, Glen Dimplex, ITI, Rolls-Royce, Denroy, SAM UK, MTC, Far UK, OxMet, Bombardier
- EPSRC Grant of £7.3M
- Total Industrial Partner support to value of £1.5M
- 10+ PDRA across the three sites.
- Academic & Industrial support brings 14 PhD studentships

Research Challenges

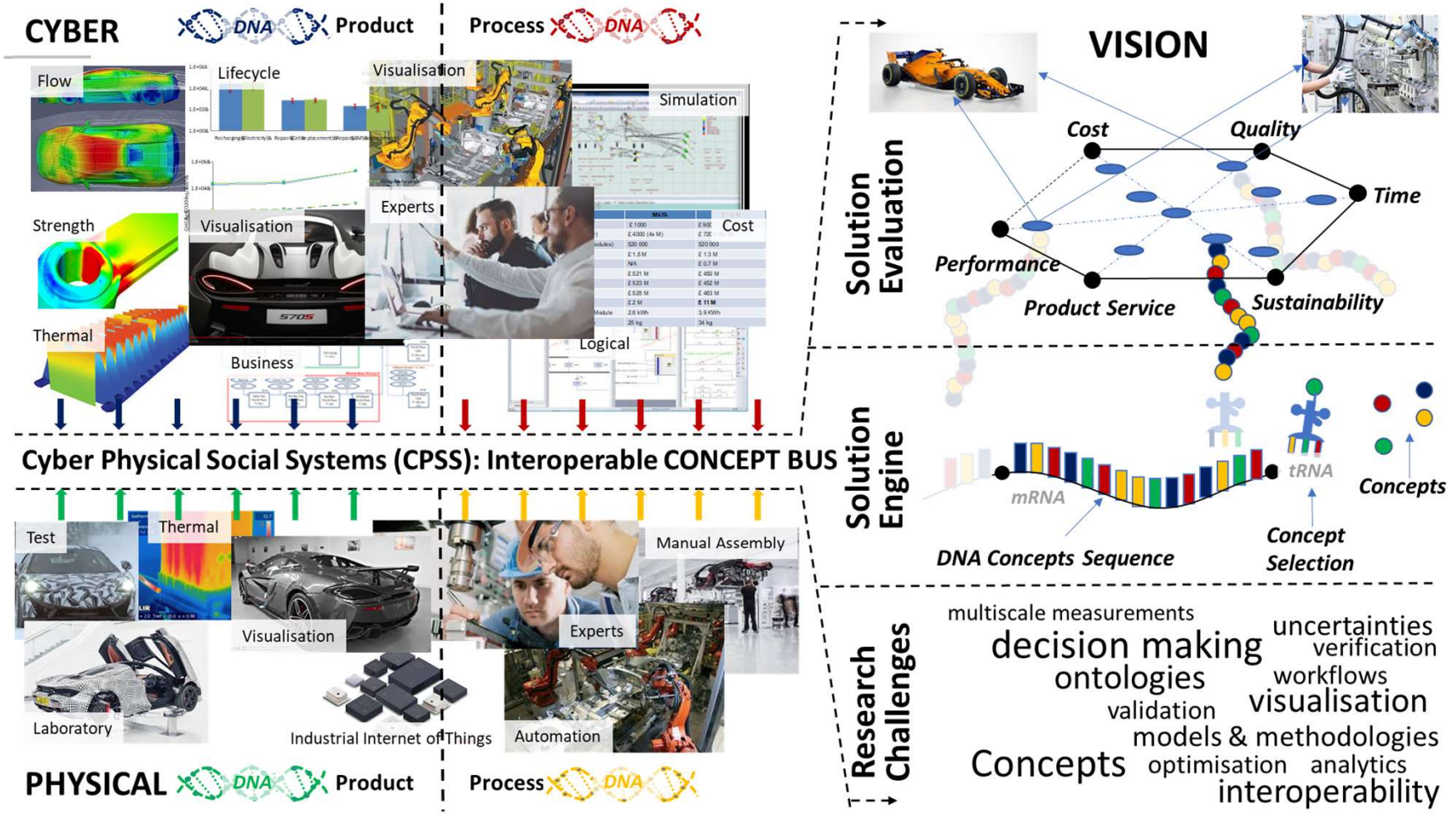
Research Challenges

- **Interoperability – CPS Design Theory**
  - How can we generate ideas and concepts rapidly such that artefacts are designed concurrently with manufacturing systems to create resilient extended enterprises with open communication throughout the whole system?
- **The Cyber World – CPS Modelling Design & Manufacture**
  - How can we represent concepts virtually such that key design characteristics driving intended behaviour are understood, coded and realised via robust, intelligently manufactured product variants?
- **The Physical World – CPS Concept to Reality**
  - What verification and validation concepts are needed to find the shortest and most beneficial pathway to physical realisation aided by a cyber-physical-socio manufacturing ecosystem?
- **The Socio World – CPS The Extended Manufacturing Enterprise**
  - How can we translate and exploit concepts in new organisational structures within a cyber-physical-socio ecosystem to accelerate evolution of design solutions across extended enterprises?

Interoperability

Re-Imagining Engineering Design

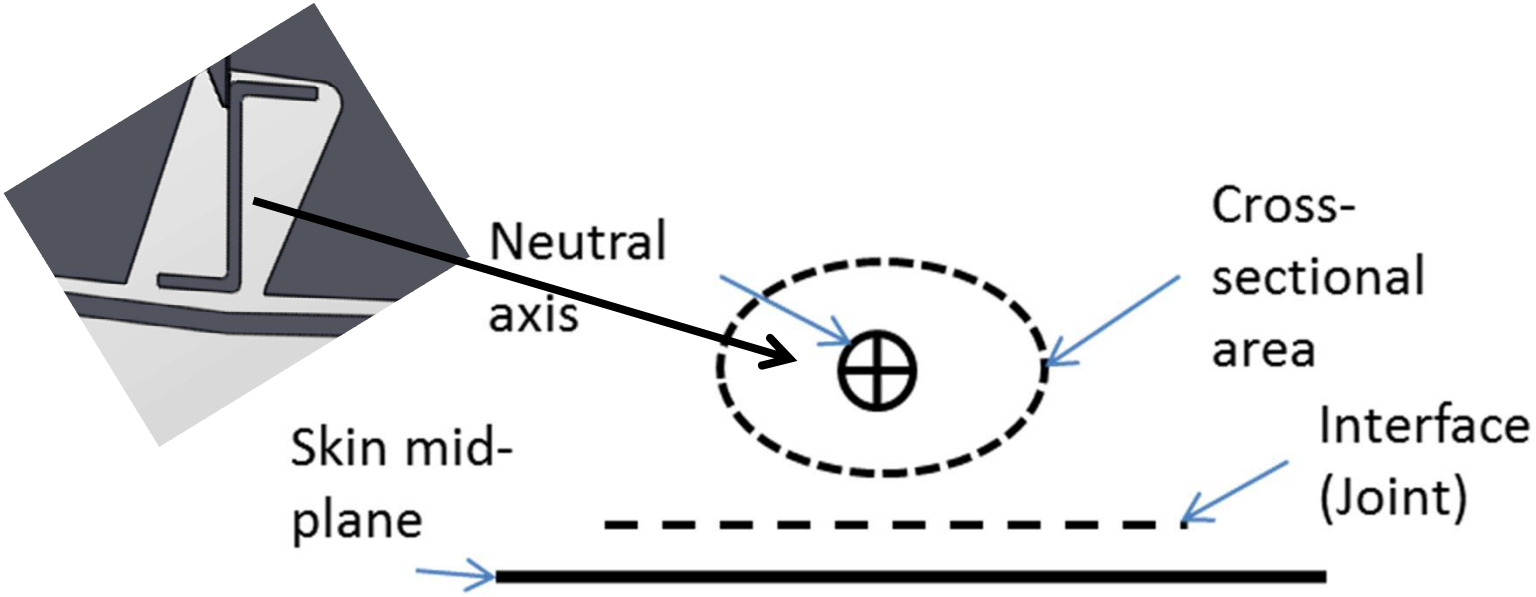
The process is very, very complex…



The Cyber World

Different actors in the system have different views and models.

Function (Intent) of the stiffener is to carry end load and a little (but preferably no) bending, supporting the skin.



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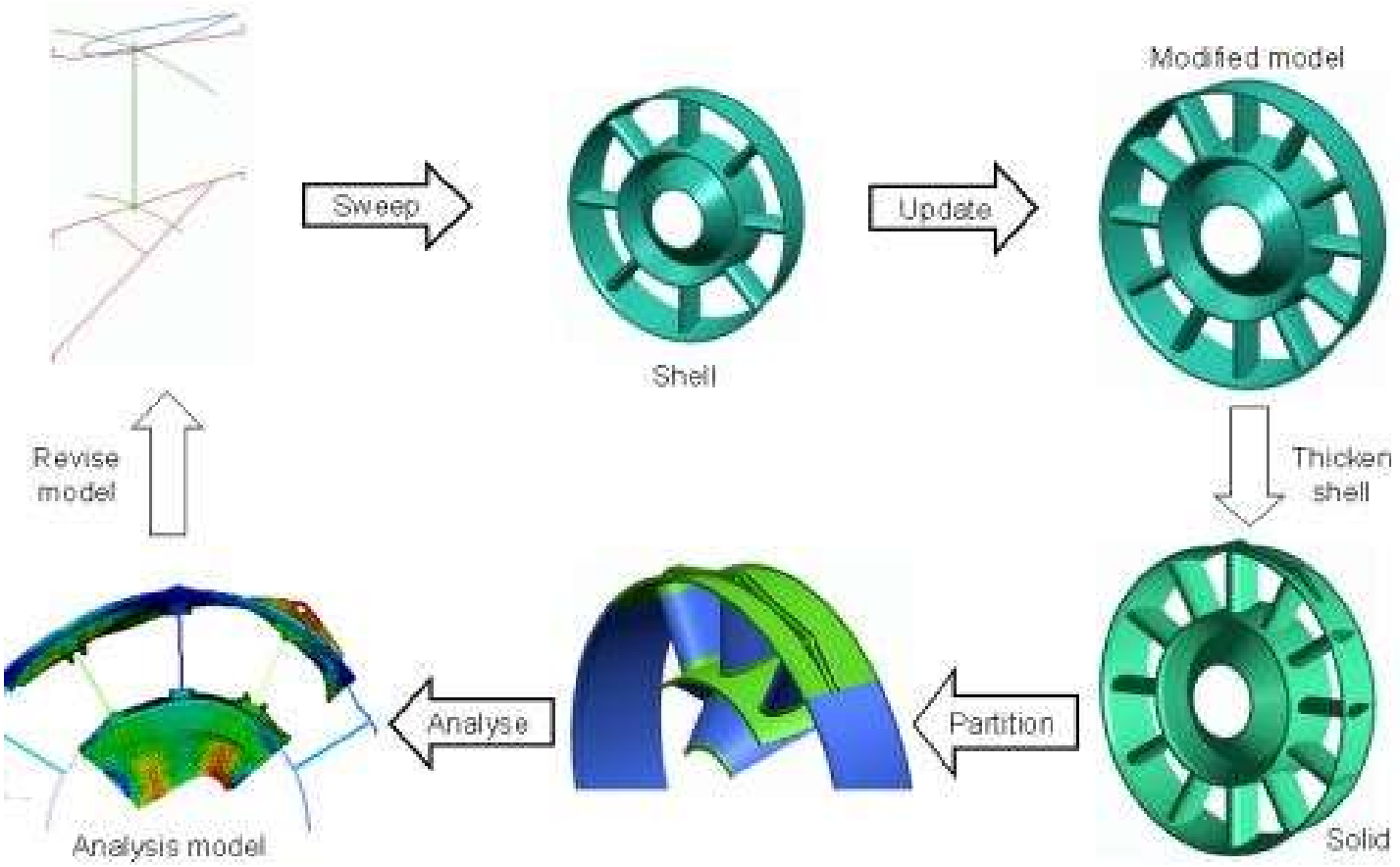
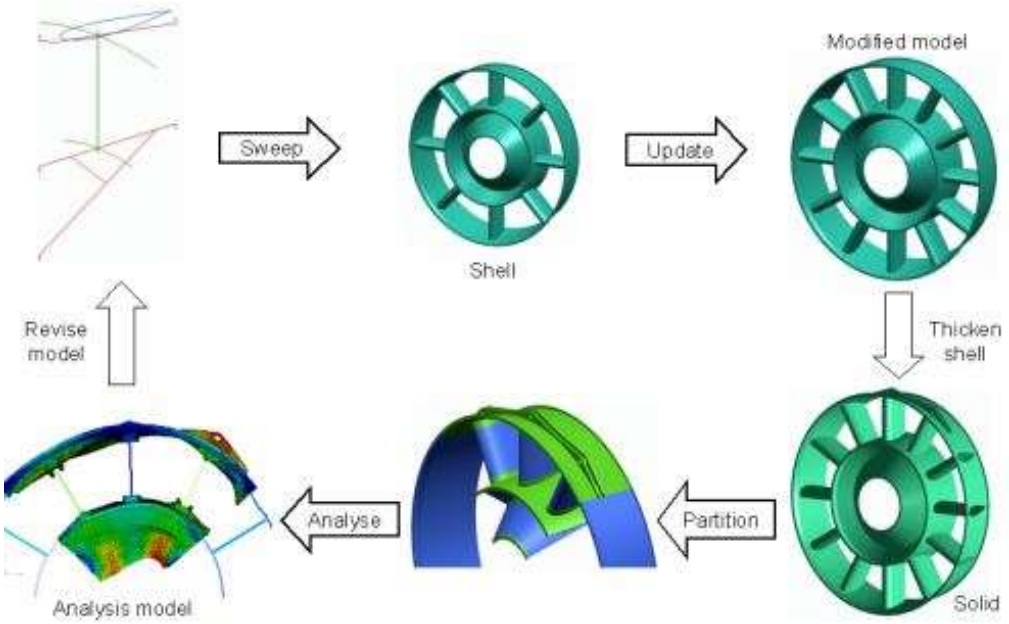
The right representation for the right decision at the right time



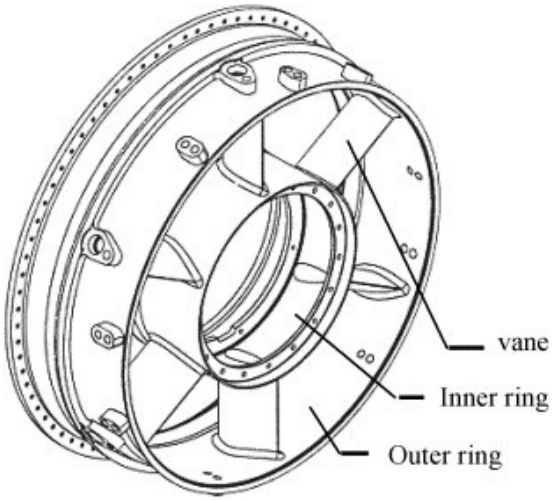
The Physical World

Component Manufacture

- Geometry is different in analysis and manufacturing



Simulation World



Manufacturing World

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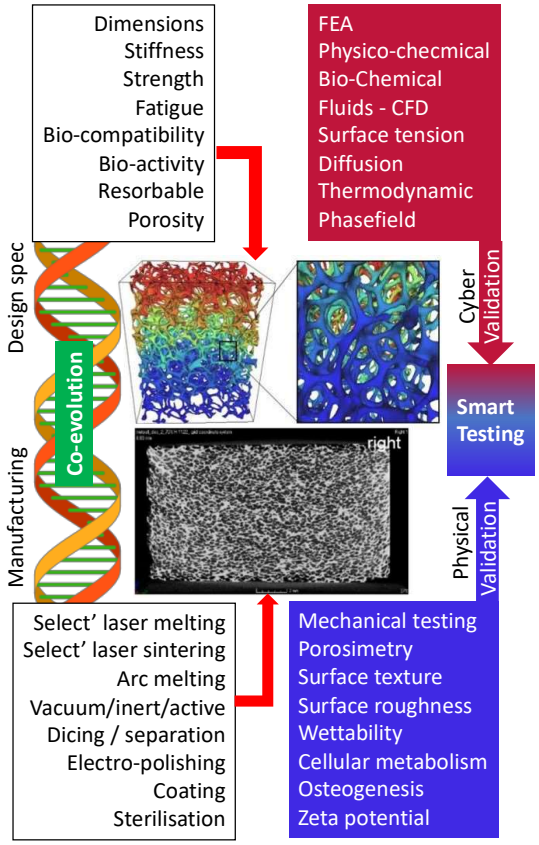
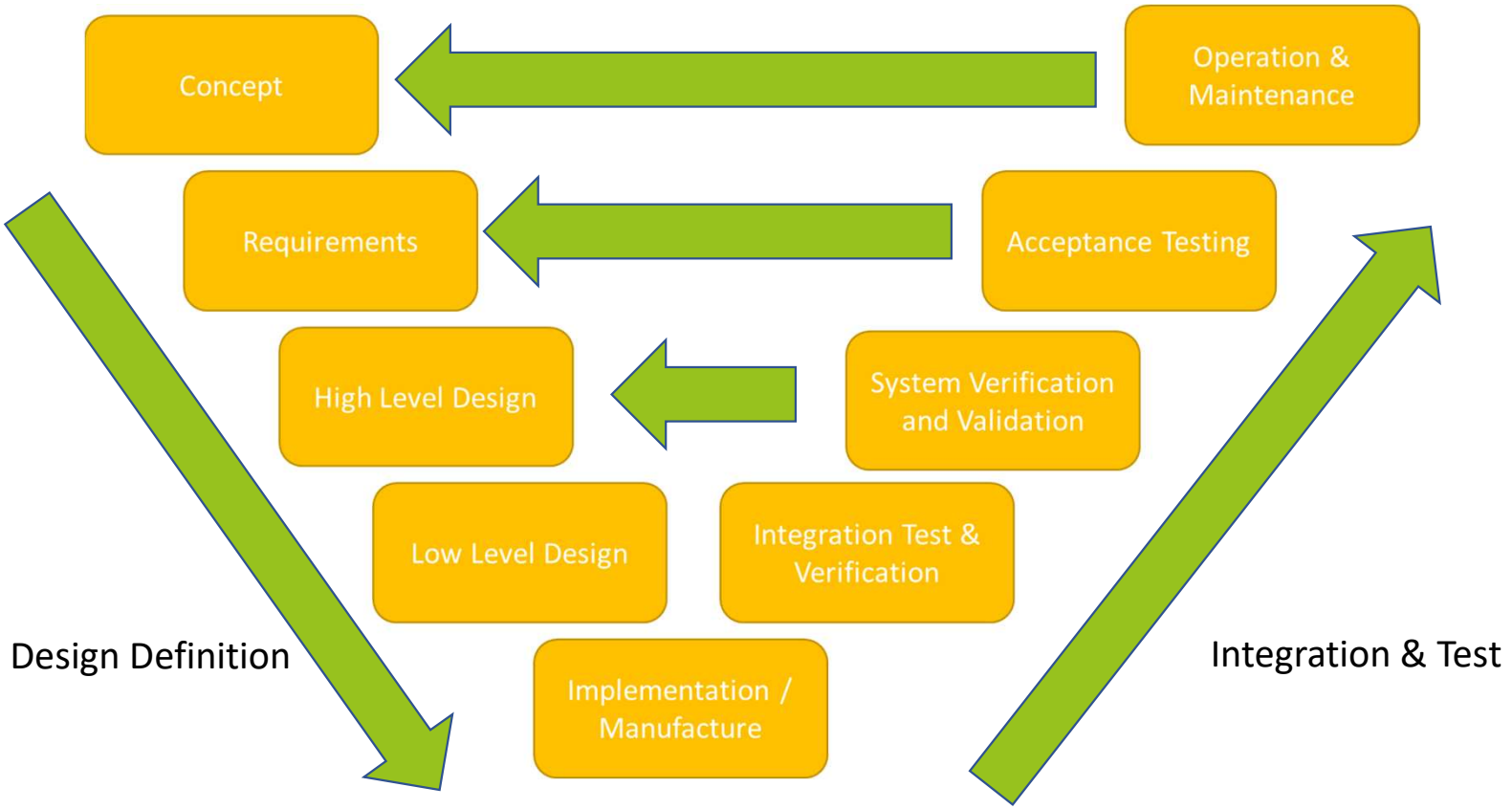
Verification and Validation

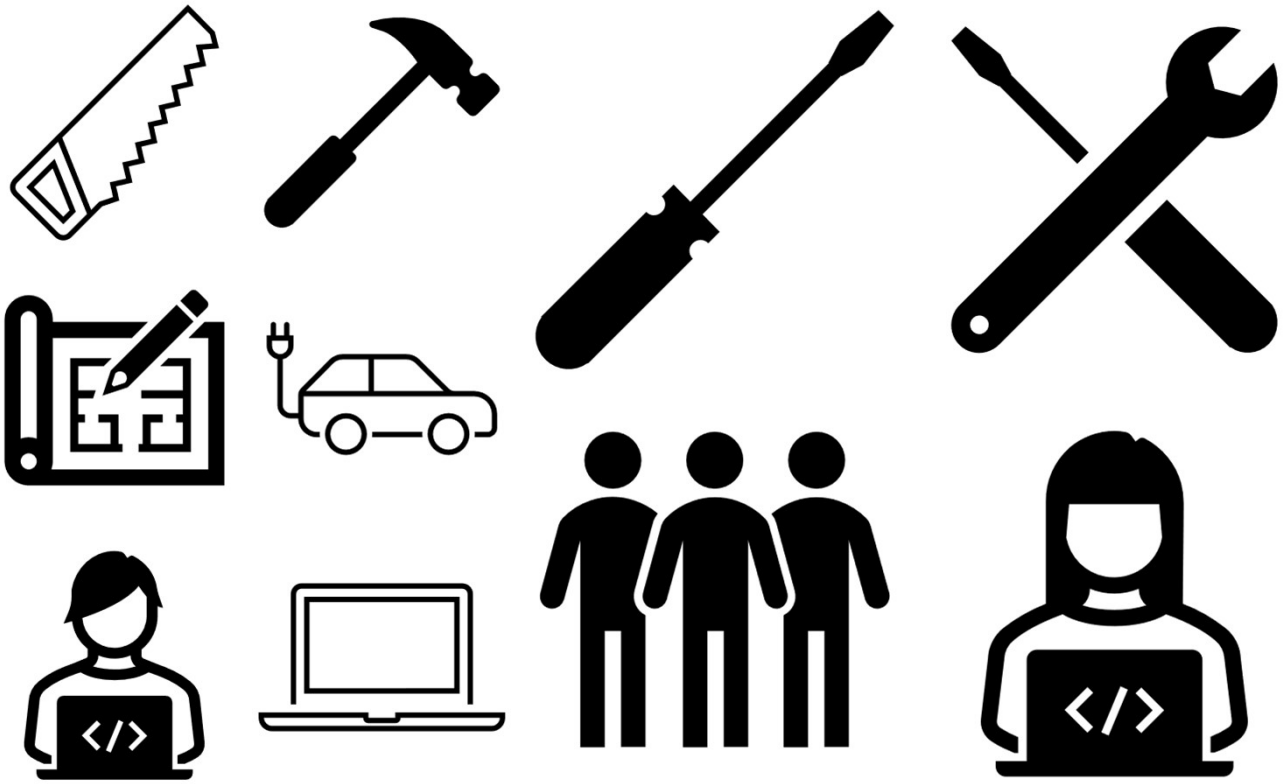


Exemplar demonstrator for Design-to-Prescription application

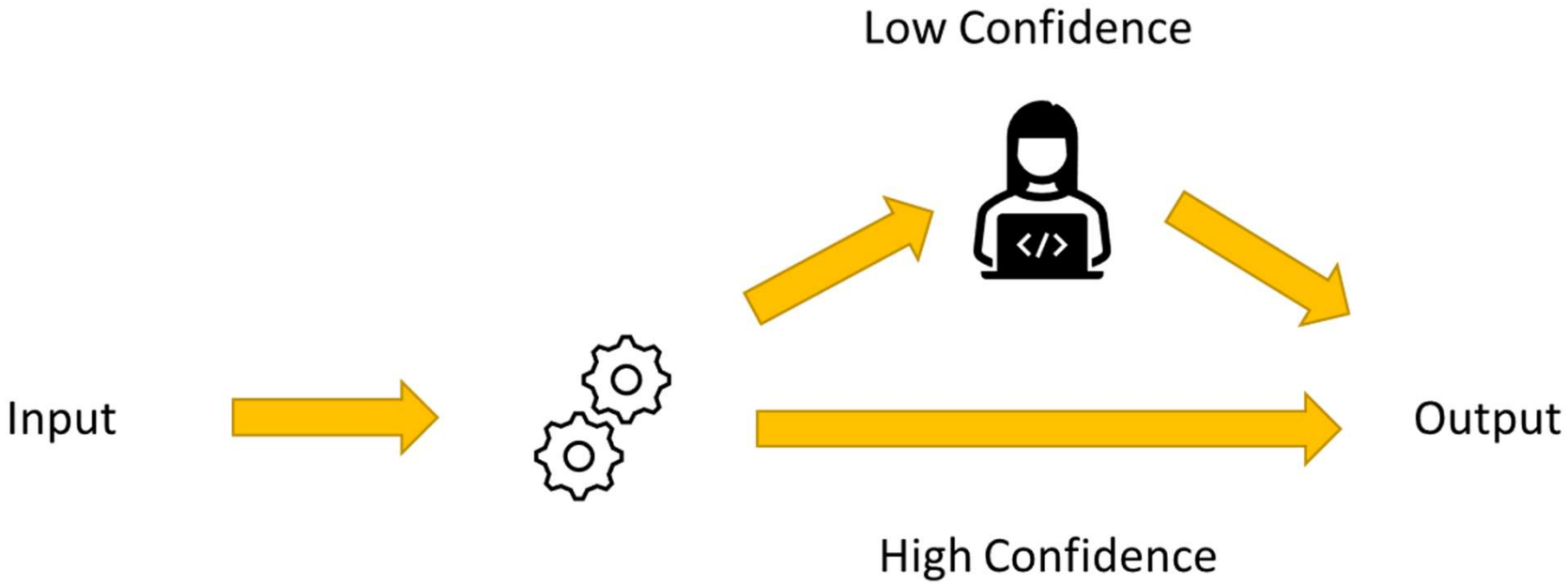


The Socio World

Re-Imagining Engineering Design



All in concert and perfectly attuned…?



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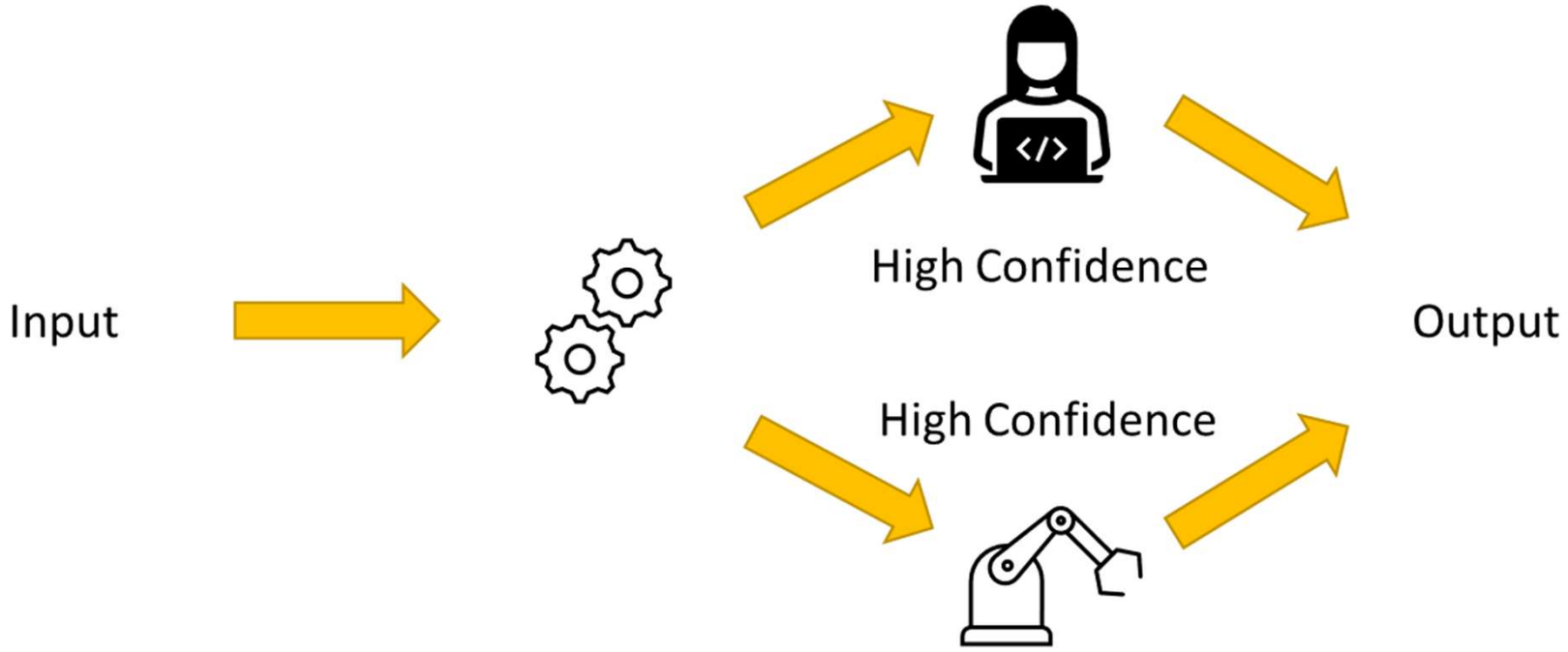
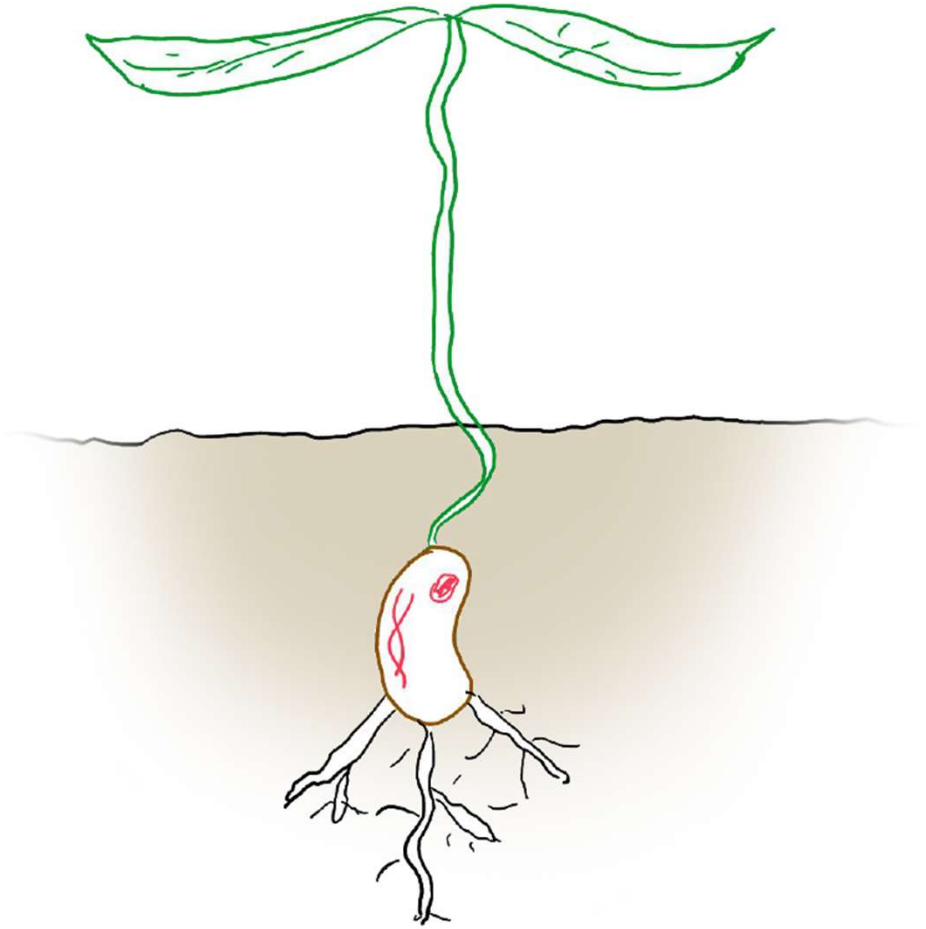
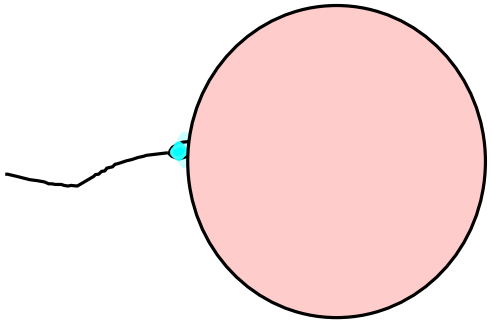


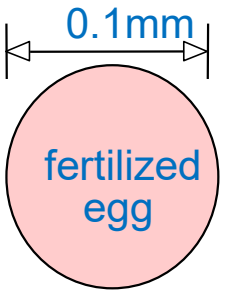
Inspiration from Nature

CONCEPT AND ETHOS

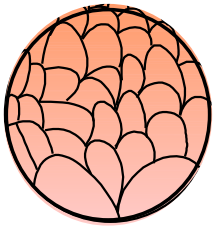


Building Complex Systems – Nature's Approach

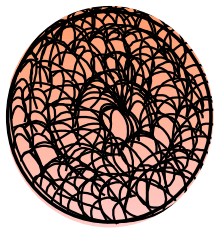




1/2 hour, 1 cell

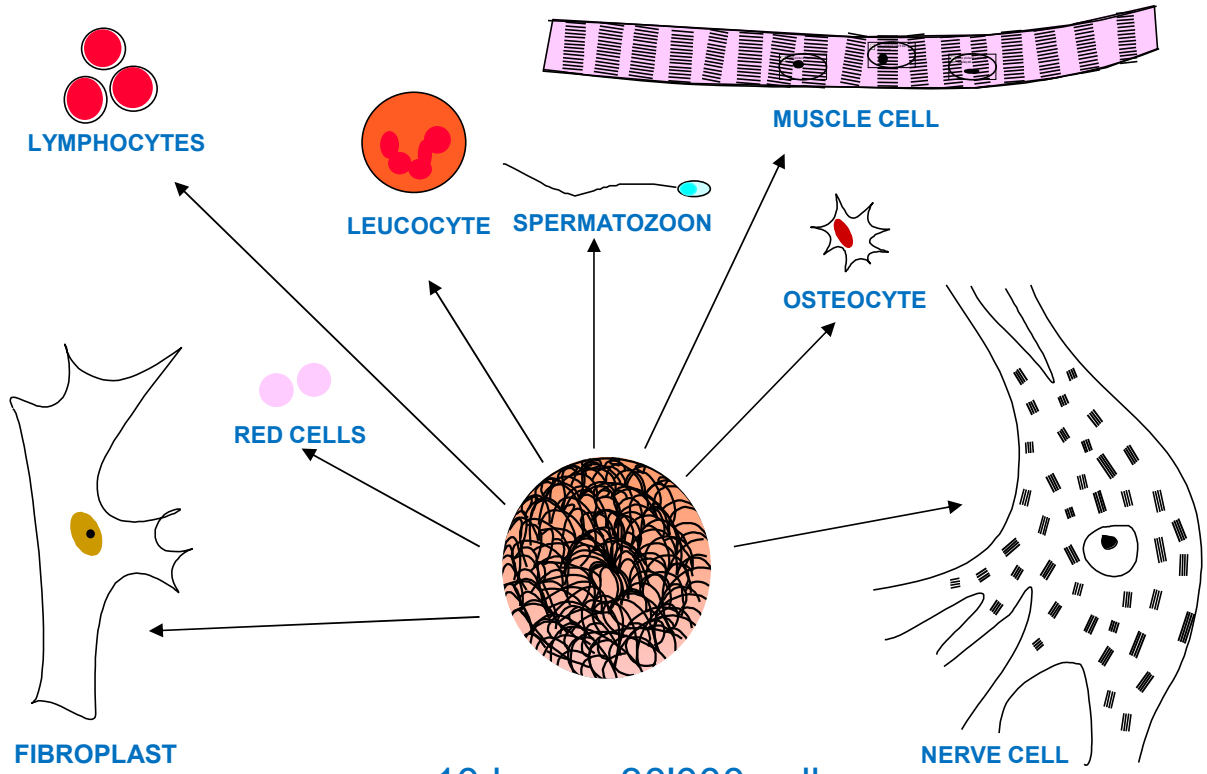


3 hours, 64 cells



6 hours, 10'000 cells

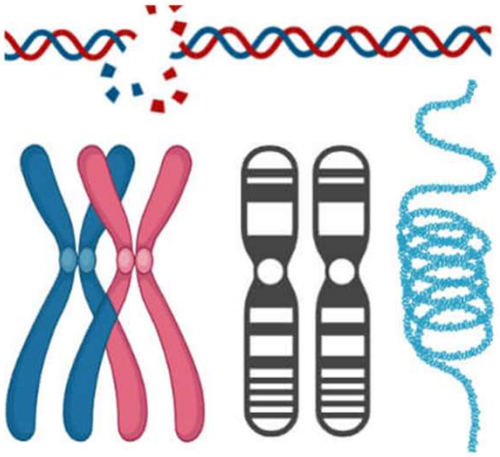
Building Complex Systems – Nature's Approach



Re-Imagining Engineering Design

GENOTYPE

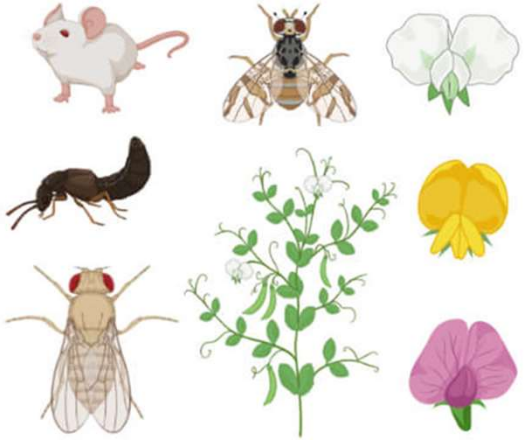
CGTTGGAACCGTGTGCCAGTGTTGG
AACCGGAAGGGACGTGGTTTTGTTG



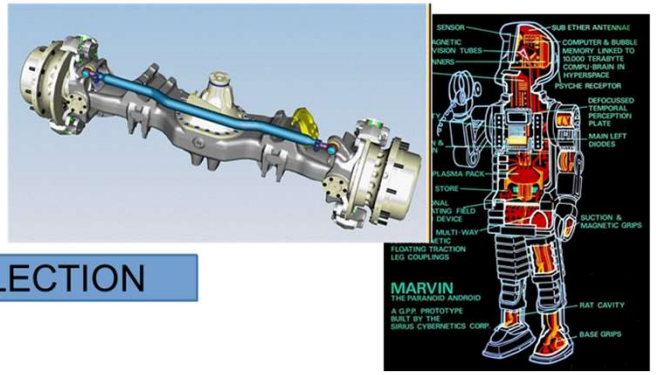
01110011001101010110101011010110111011000110010101
00111001100101011011001100110011001010101100

DEVELOPMENT

EVOLUTION



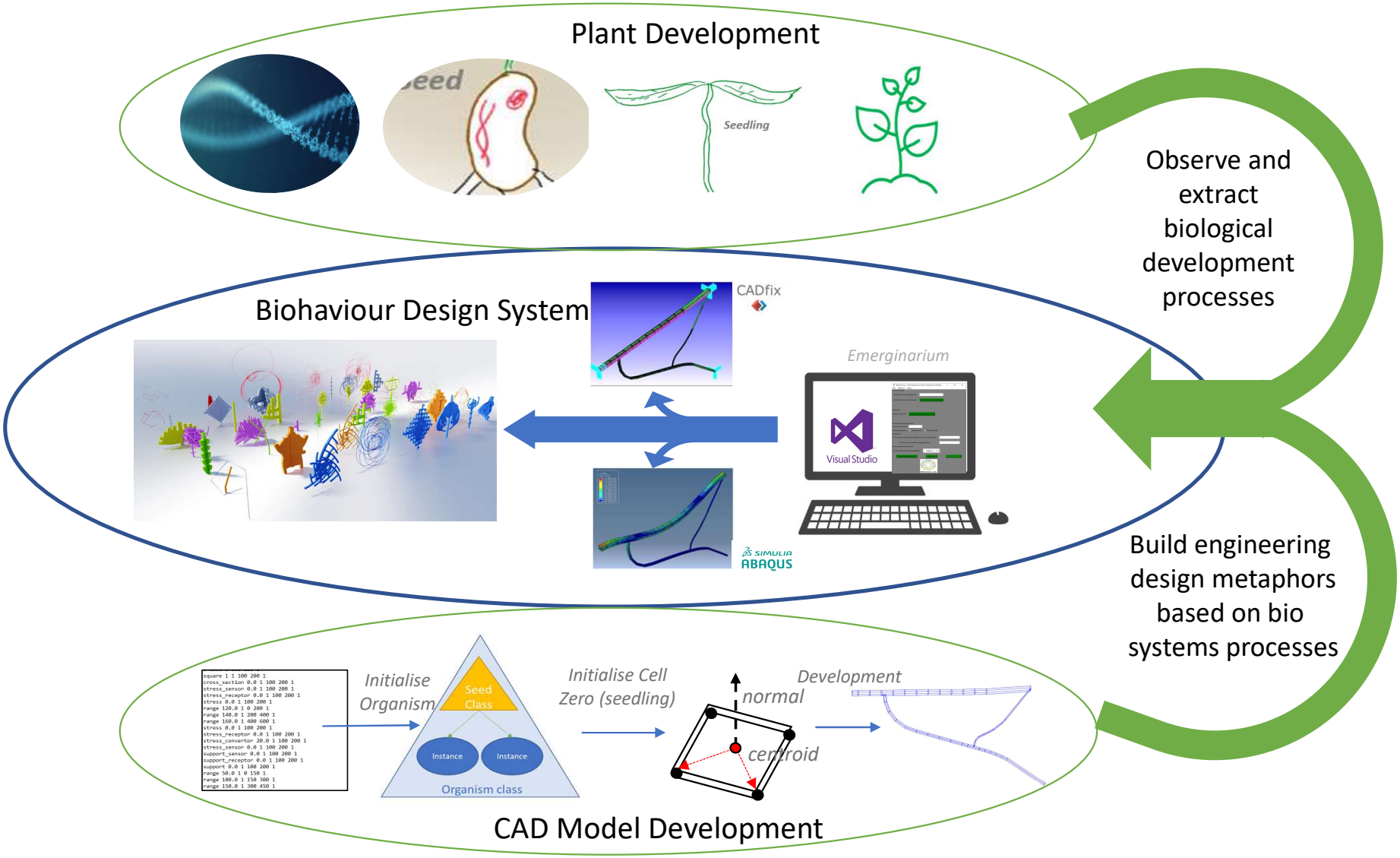
PHENOTYPE



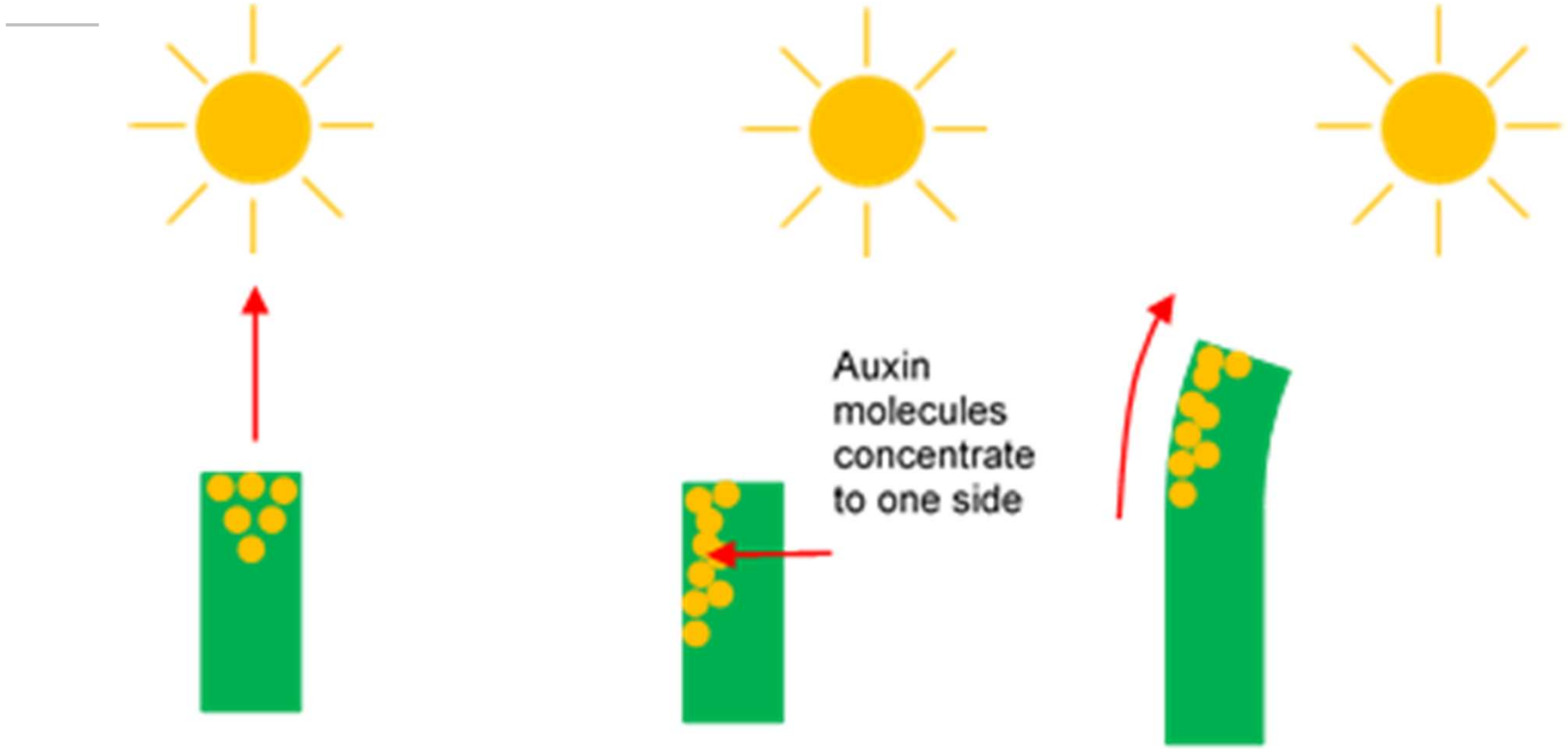
MUTATION

SELECTION

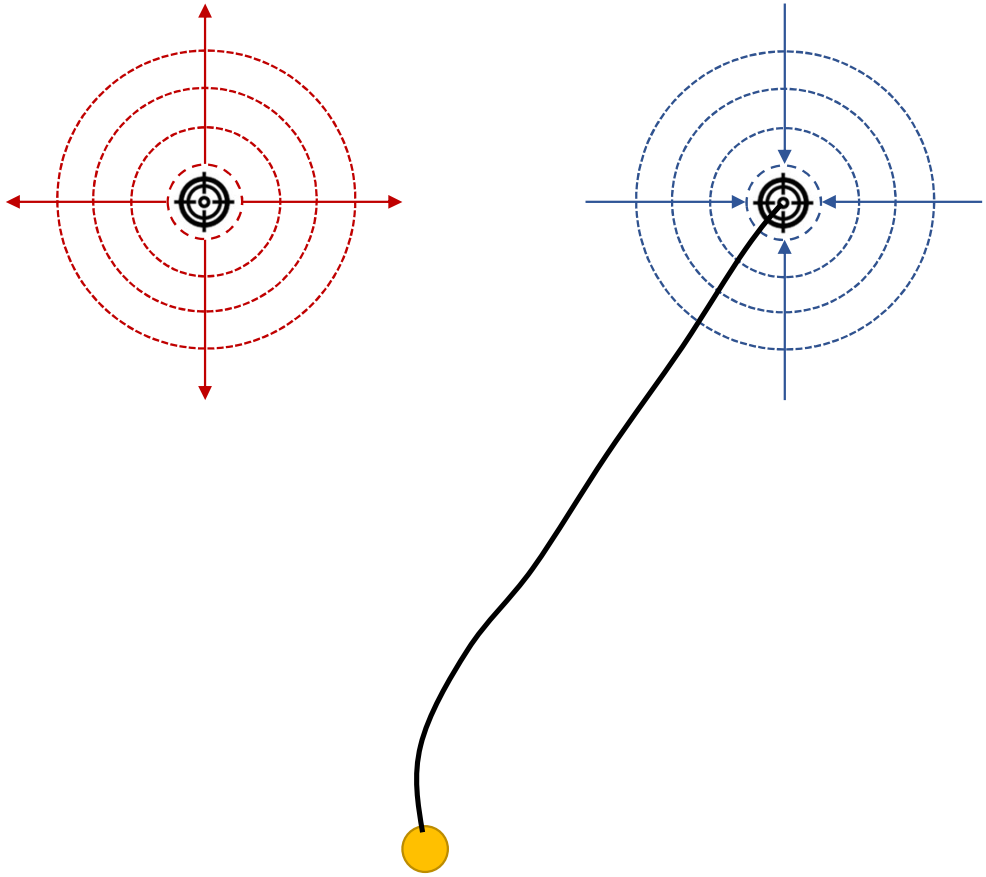
Generative Design for Additive Manufacturing Using A Biological Development Analogy



Re-Imagining Engineering Design



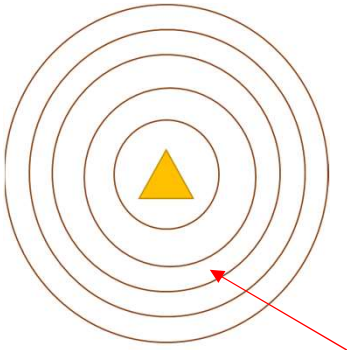
Re-Imagining Engineering Design



Support Sensor: Receptor & Convertor in Primary Growth

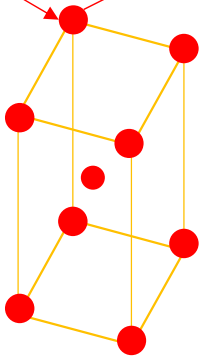
- Located at each vertex in the cell – face and cell centroid
- Sense stimulus, receive field strength and top-up hormone in vertices
- Encourage organism development towards or away from stimulus

```
support_sensor 0.0 1 100.0 200.0 1
support_receptor 0.0 1 100.0 200.0 1
support 0.0 1 100.0 200.0 1
range 50.0 1 0.0 150.0 1
range 100.0 1 150.0 300.0 1
range 150.0 1 300.0 450.0 1
range 175.0 1 450.0 600.0 1
support 0.0 1 450.0 600.0 1
support_receptor 0.0 1 100.0 200.0 1
support_convertor 20.0 1 0.0 200.0 1
support_sensor 0.0 1 100.0 200.0 1
```

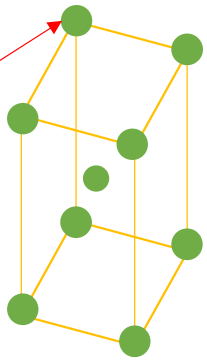


Support 'attraction' field

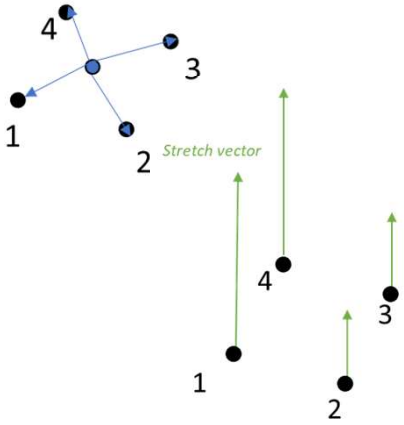
```
support_receptor 0.0 1 100.0 200.0 1
support 0.0 1 100.0 200.0 1
range 50.0 1 0.0 150.0 1
range 100.0 1 150.0 300.0 1
range 150.0 1 300.0 450.0 1
range 175.0 1 450.0 600.0 1
support 0.0 1 450.0 600.0 1
support_receptor 0.0 1 100.0 200.0 1
```



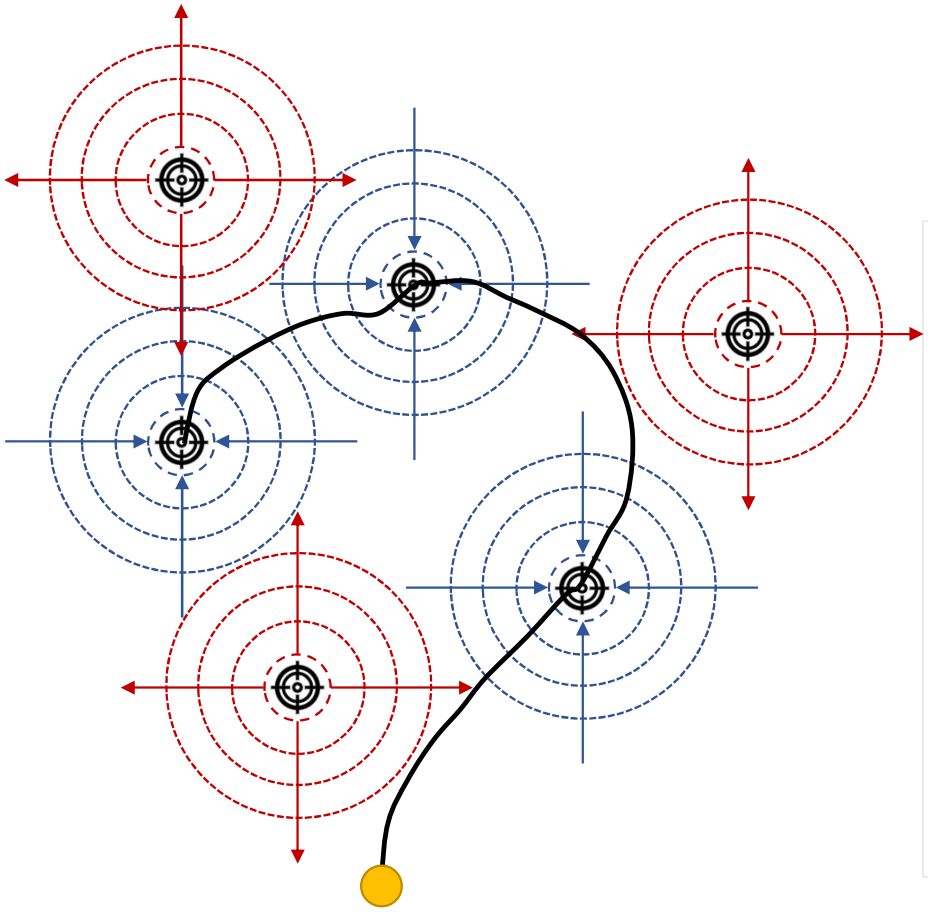
```
support_receptor 0.0 1 100.0 200.0 1
support 0.0 1 100.0 200.0 1
range 50.0 1 0.0 150.0 1
range 100.0 1 150.0 300.0 1
range 150.0 1 300.0 450.0 1
range 175.0 1 450.0 600.0 1
support 0.0 1 450.0 600.0 1
support_receptor 0.0 1 100.0 200.0 1
support_convertor 20.0 1 0.0 200.0 1
```

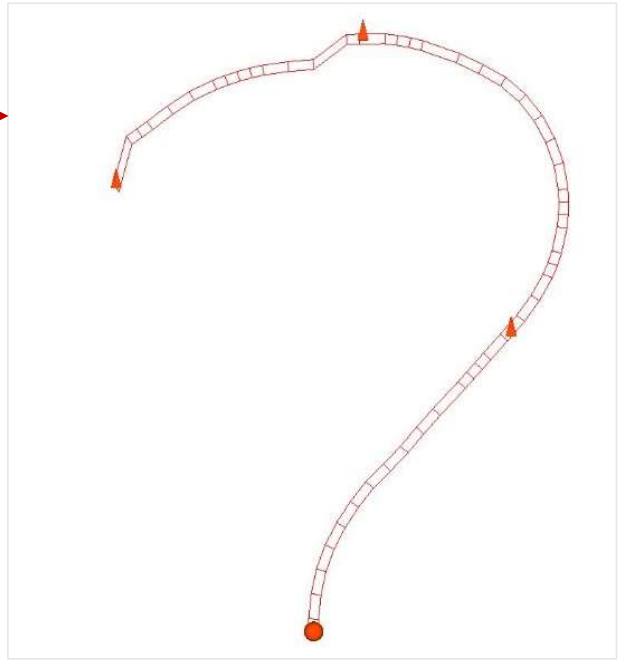


Growth

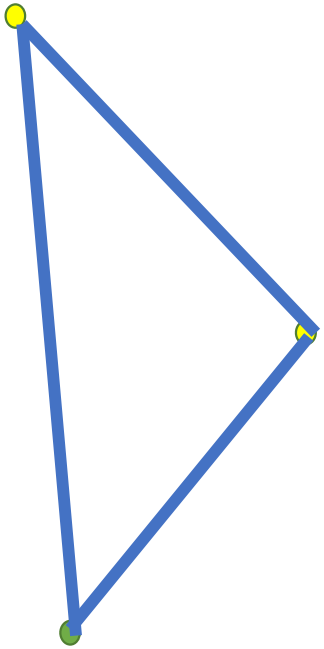


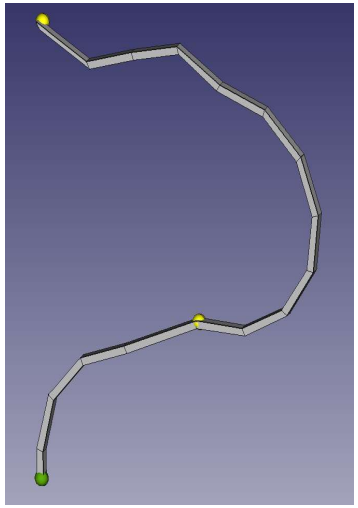
Re-Imagining Engineering Design



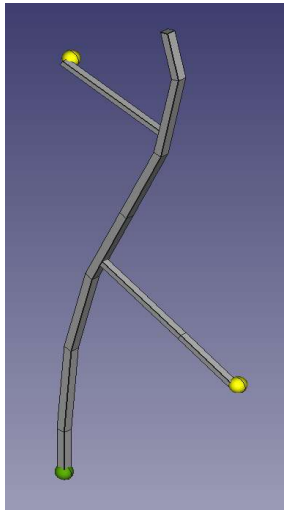


Creating variation & innovation

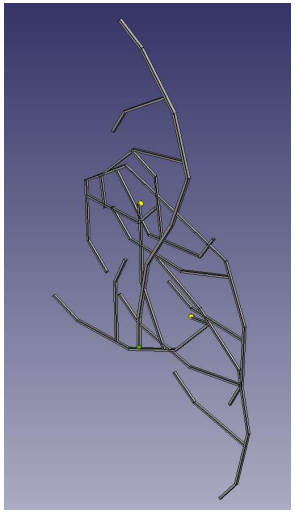


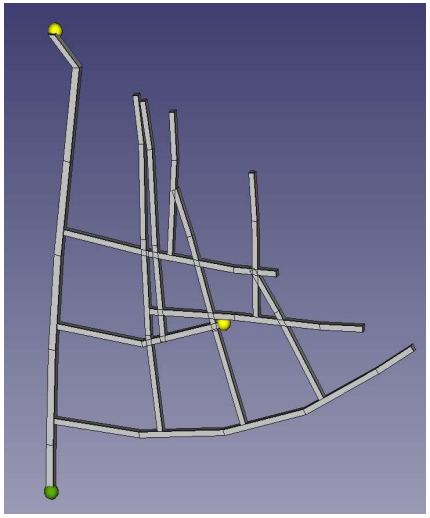


MVP1.0 – No Budding
2 Supports – Equal field strength

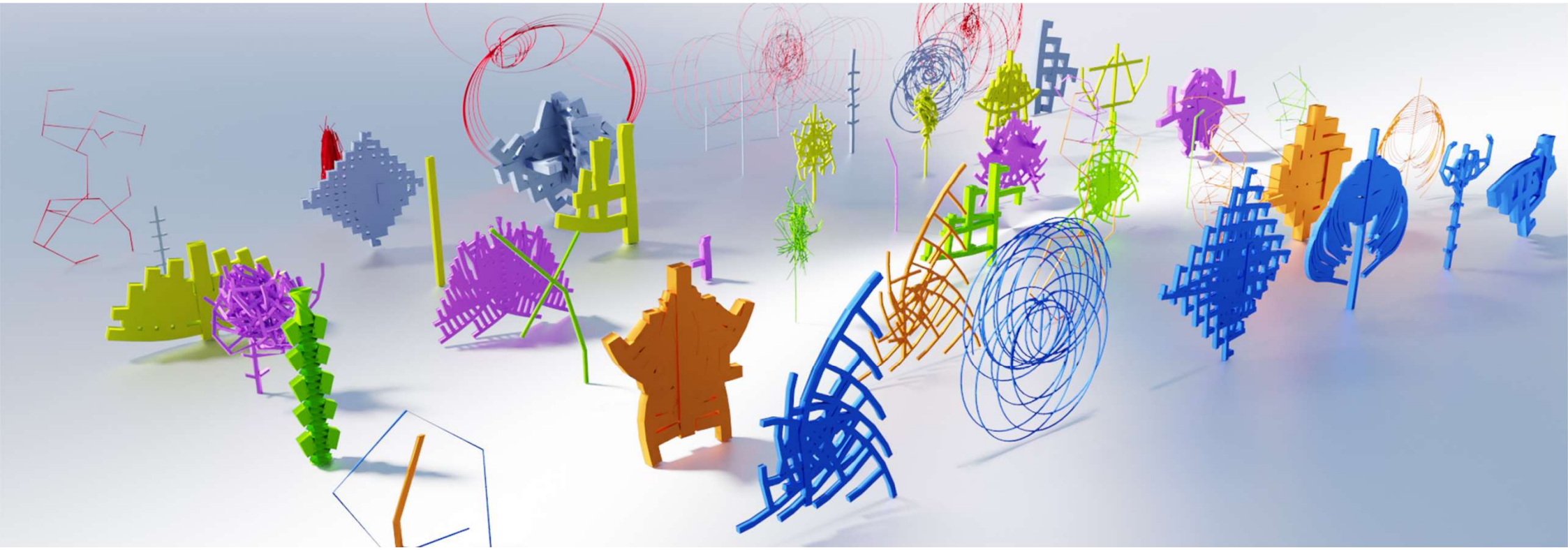


Length - 10





Length - 10
Bud Check - 45
Support Convertor - 5

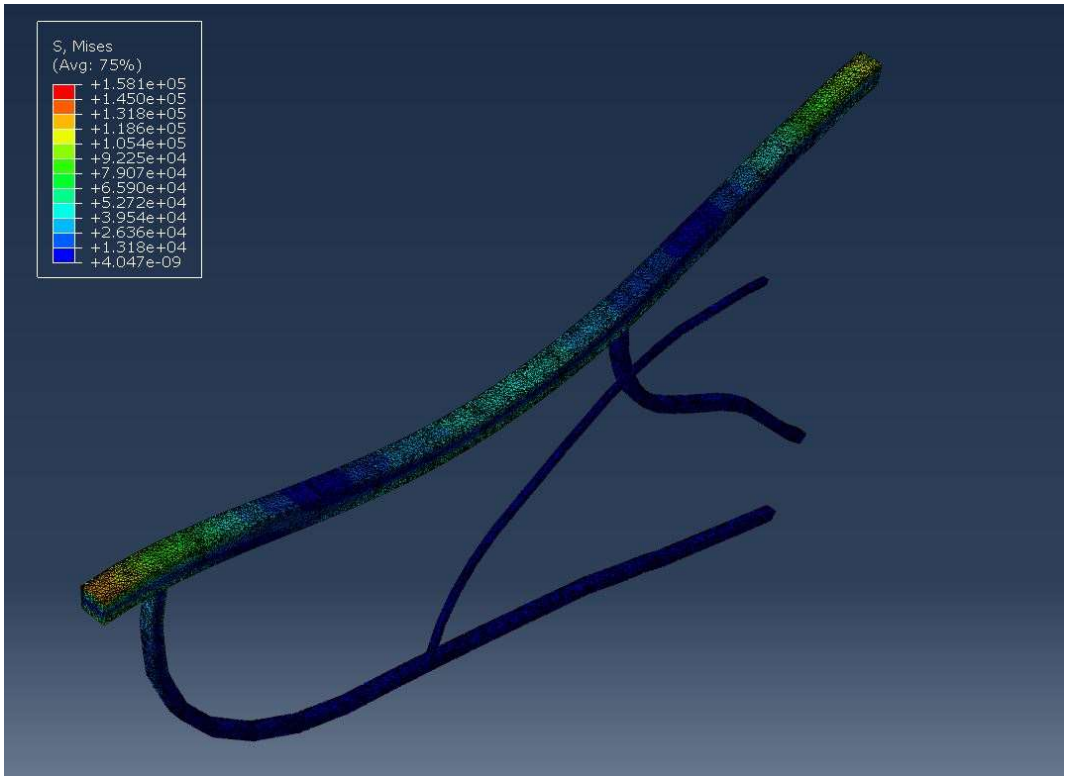


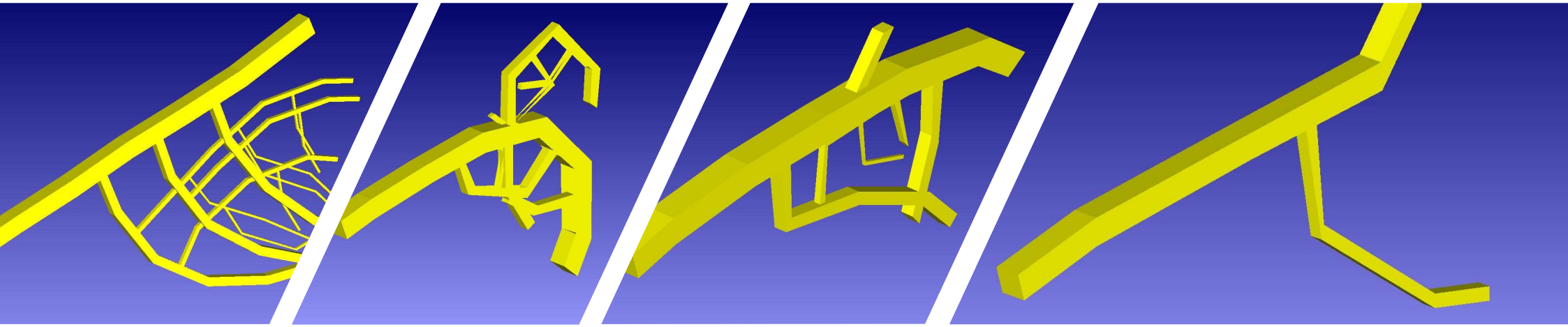
Populations with variation

- Requires ability to grow (develop) in the environment & be sensitive to the environment

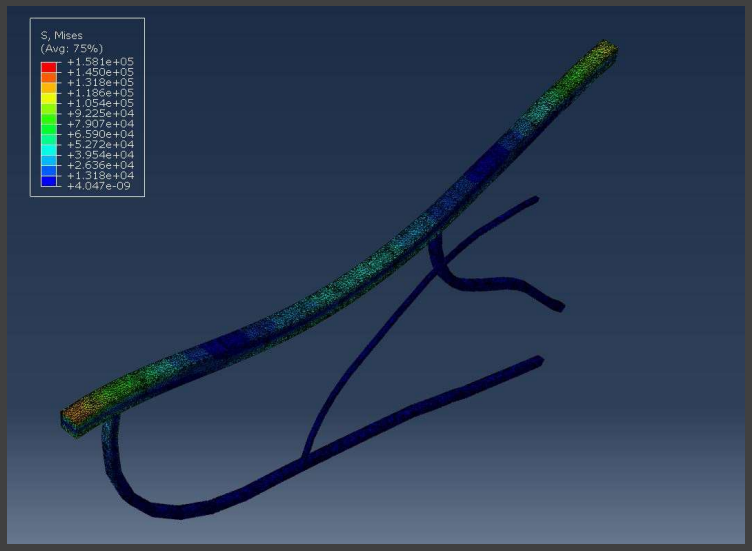
Re-Imagining Engineering Design

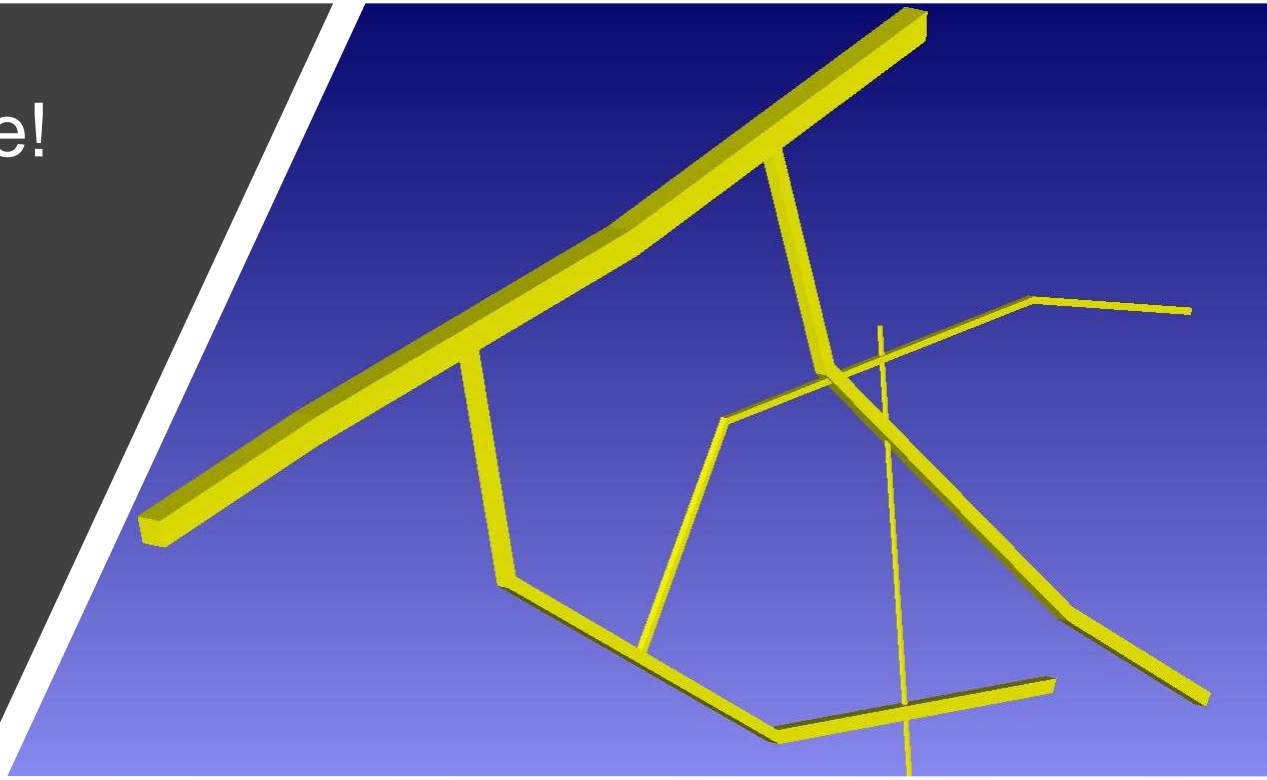
Shelf Bracket





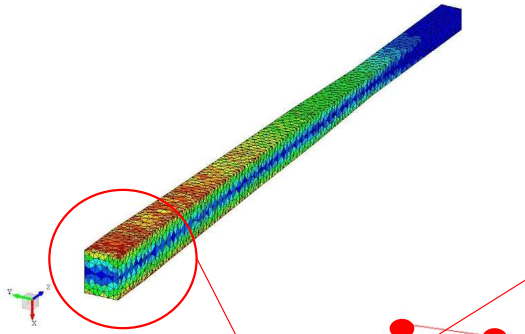
Many phenotypes emerge!



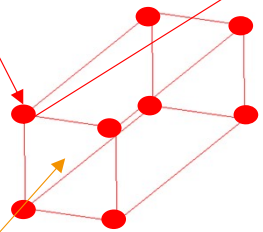


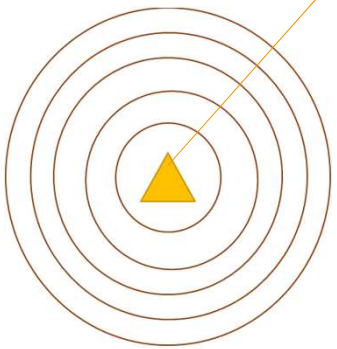
Example – Dealing with Surface Treatments/Coatings

Accounting for Manufacturing process in product geometry



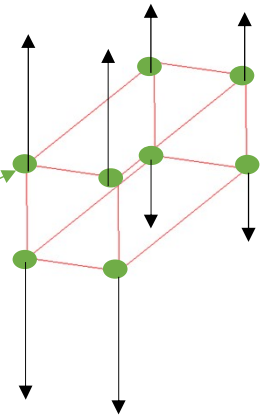
```
strain_receptor 0.0 1 100.0 200.0 1
strain 0.0 1 0.0 1.0 1
range 1 1 0.001 0.005 1
range 5 1 0.005 0.01 1
range 10 1 0.01 0.02 1
range 15 1 0.02 0.03 1
range 20 1 0.03 0.04 1
range 30 1 0.04 0.05 1
range 40.0 1 0.05 0.06 1
range 50.0 1 0.06 0.07 1
range 80.0 1 0.07 0.1 1
range 100.0 1 0.1 0.5 1
strain 0.0 1 100.0 200.0 1
strain receptor 0.0 1 100.0 200.0 1
```

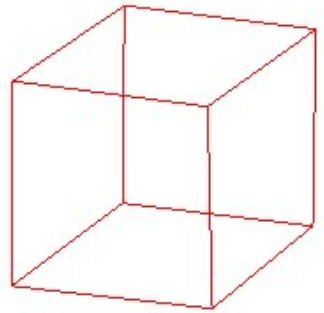




Environment Element representing a finishing process can be treated in exactly the same way

```
strain_receptor 0.0 1 100.0 200.0 1
strain 0.0 1 0.0 1.0 1
range 1 1 0.001 0.005 1
range 5 1 0.005 0.01 1
range 10 1 0.01 0.02 1
range 15 1 0.02 0.03 1
range 20 1 0.03 0.04 1
range 30 1 0.04 0.05 1
range 40.0 1 0.05 0.06 1
range 50.0 1 0.06 0.07 1
range 80.0 1 0.07 0.1 1
range 100.0 1 0.1 0.5 1
strain 0.0 1 100.0 200.0 1
strain_receptor 0.0 1 100.0 200.0 1
strain_convertor 100.0 1 0.0 100.0 1
```



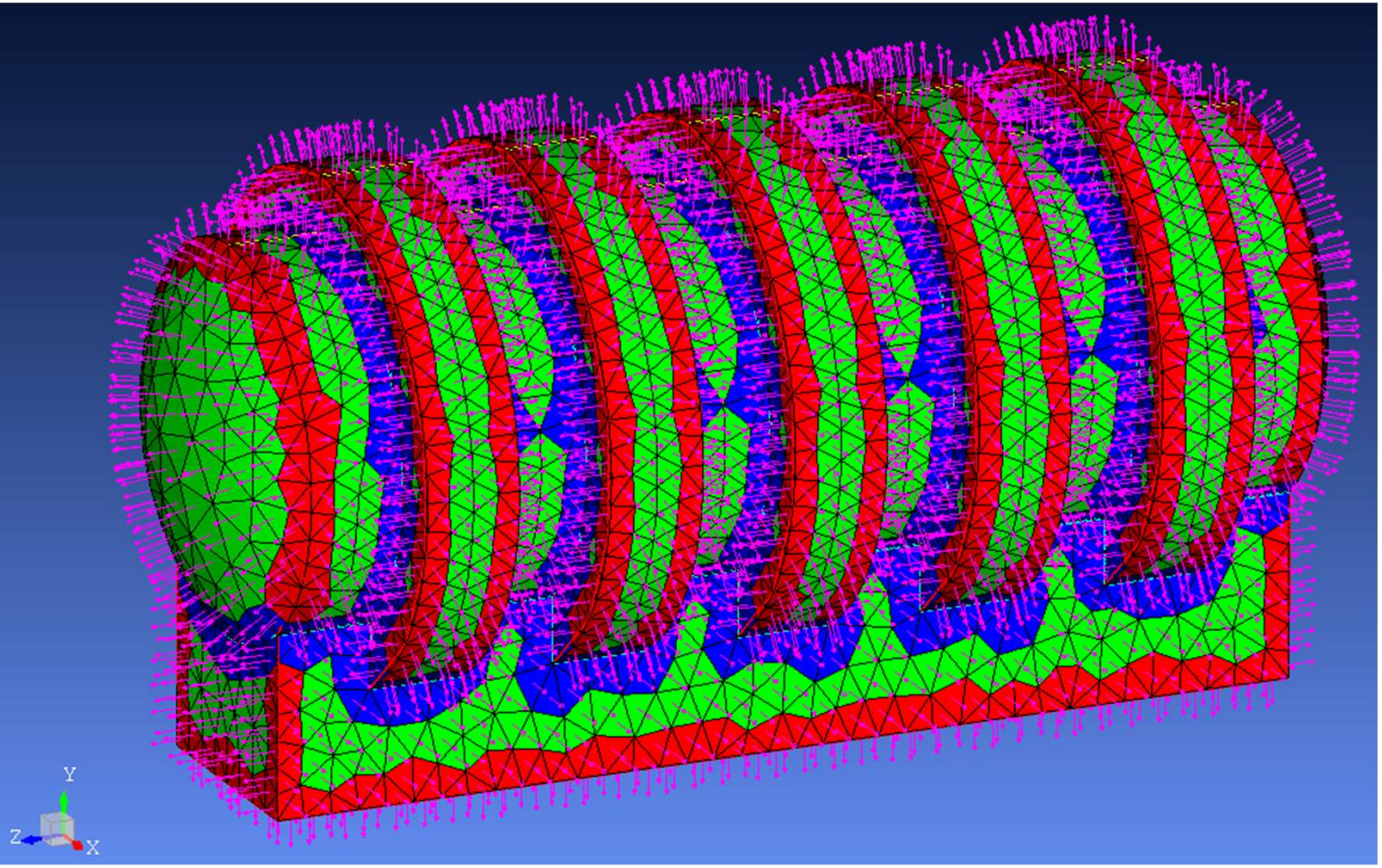


Practical Example – Storage Tank Design & Manufacture

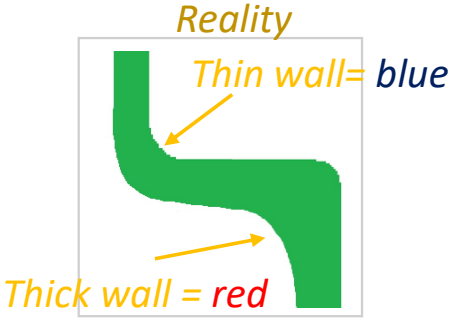
Storage Tank Design

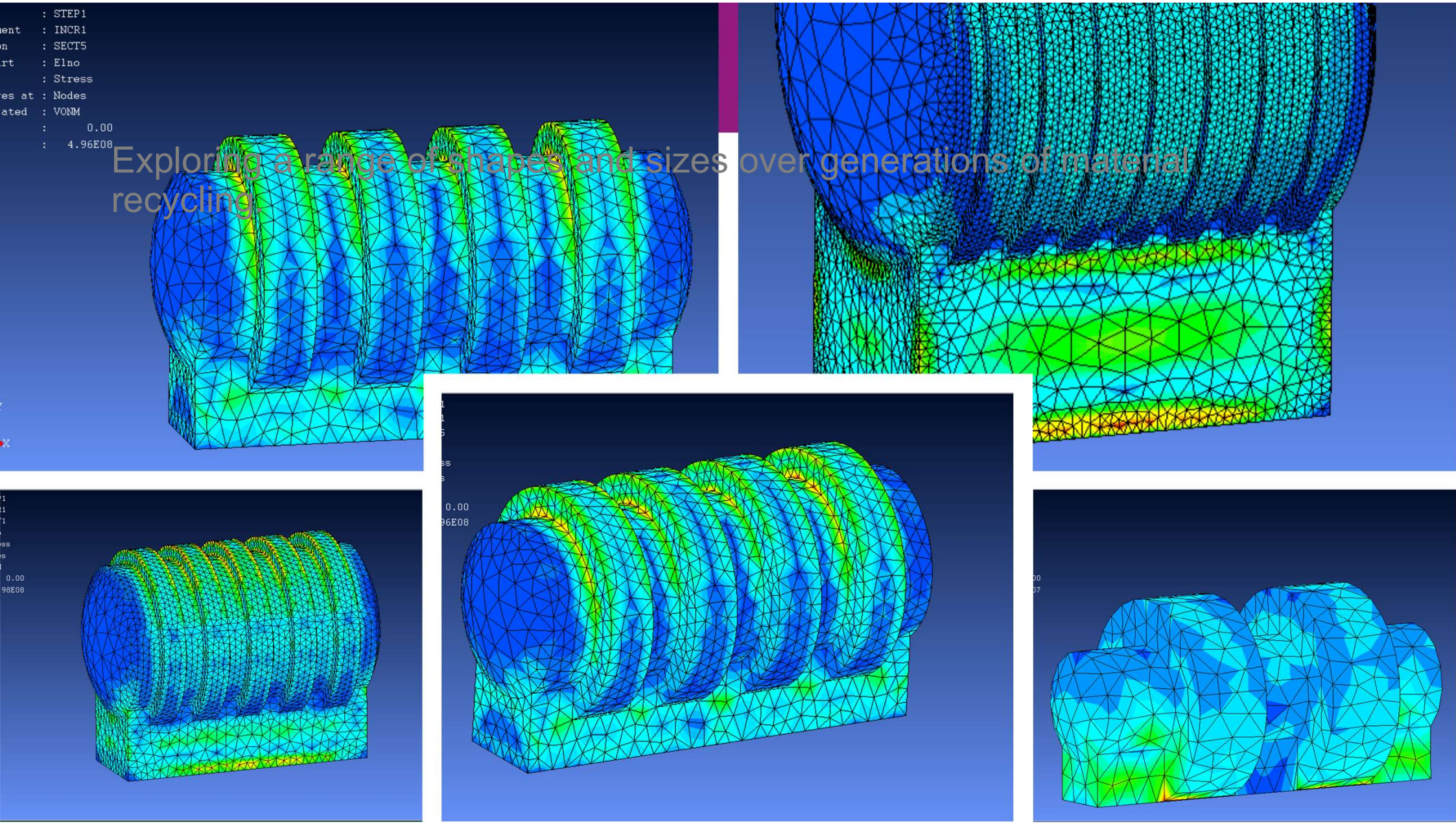
- What would a storage tank look like if recycled material is used and the aim is to minimise (or have zero) waste in the manufacturing process?

Re-Imagining Engineering Design



- Manufacturing information relating to wall thickness is fed back into the design models.
- Genes in this case align to key geometry design parameters.




: STEP1
: INCR1
: SECT5
: Elno
: Stress
: Nodes
: VONM
: 0.00
: 4.96E08
Exploring a range of shapes and sizes over generations of material recycling.

Conclusions

Take away Points

- Going beyond current paradigms in manufacturing needs new design processes
- RIED – Re-Imagining Engineering Design is a large scale programme re-thinking this at a fundamental level
- The approach is bio-inspired, we grow structures like plants.
- The manufacturing system & product evolve together, each attuned to the other.

Thanks to…

Re-Imagining Engineering Design

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UKRI Engineering and Physical Sciences Research Council

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Thank You for Listening

And remember…….

Imagination is the only weapon in the war against reality.”
— Lewis Carroll, *Alice in Wonderland*