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New manufacturing techniques for optimised fibre architectures

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This approach will not be constrained to architectures that can be produced using existing manufacturing technologies such as weaving or braiding

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Objectives

- Establish computational framework for textile preform optimization not limited to existing processes
- Via a series of case studies, identify classes of materials with improved properties over existing forms
- Develop new or modified textile preform technologies to realize these material forms
- Validate predicted properties and demonstrate their utility to materials suppliers and end-users

What is an optimised fibre architecture?

Motivation, existing solutions

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What is an optimised fibre architecture?

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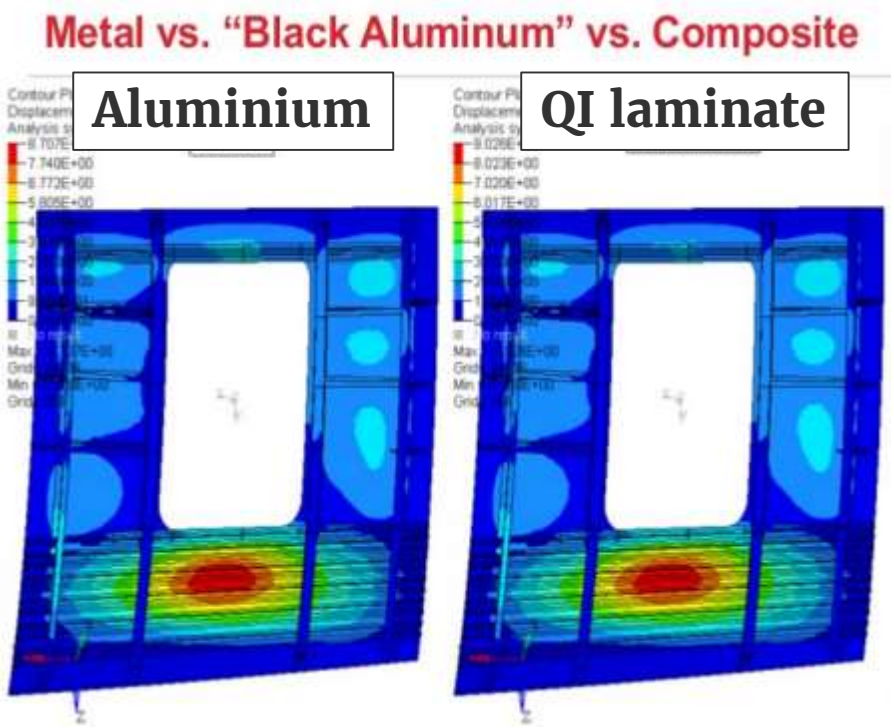
Conservative composite design – "black aluminium"

- "Black aluminium" – quasi-isotropic laminates without load-specific design
- Overdesign of components



12% mass saving

D. Warren "Advanced Design, Analysis and Optimization of Composite Structures", Altair ATCx Conference, 2015

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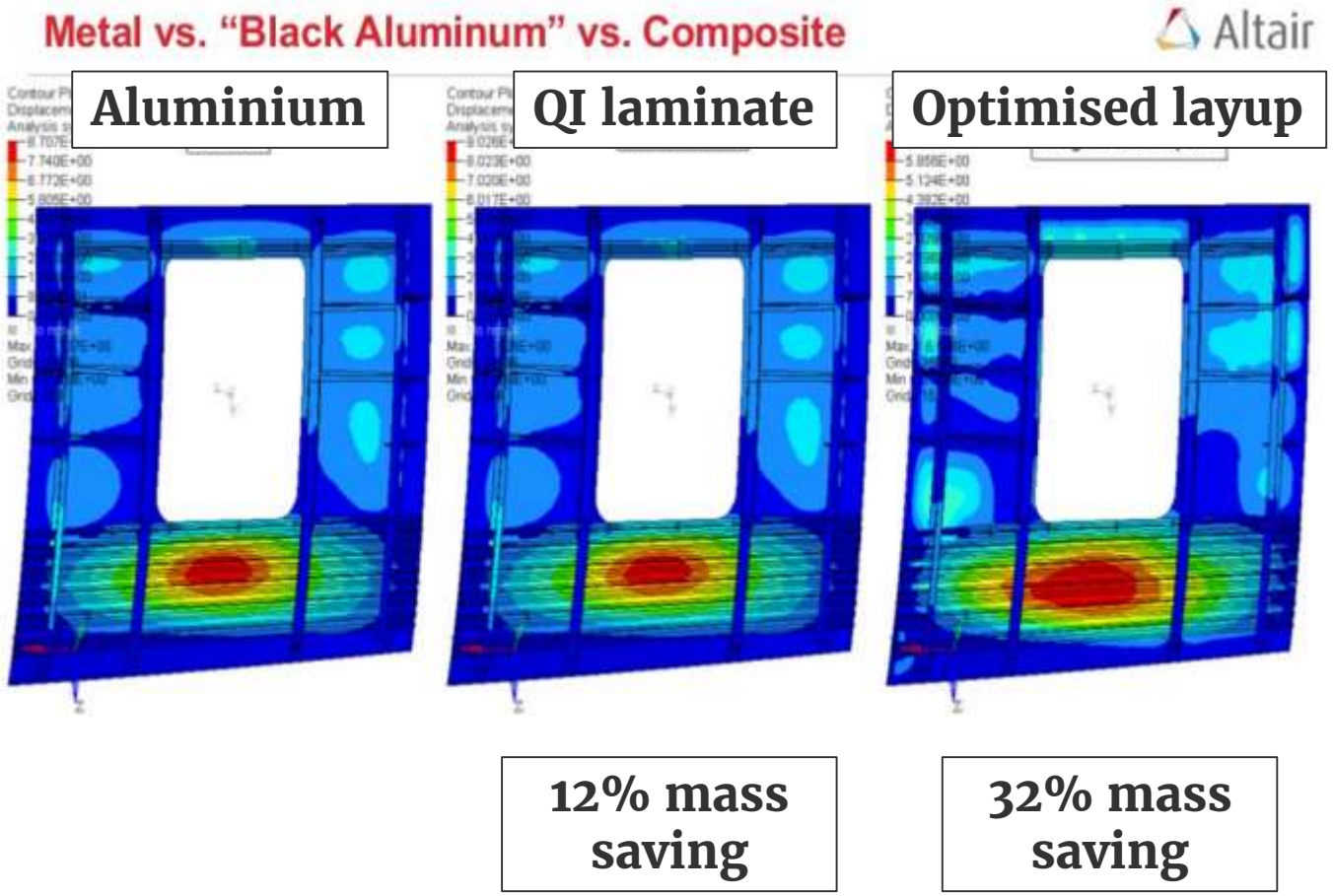
"Classical" optimisation of composite design

- Optimisation of ply sequence (layup)
- Load-specific optimisation of ply orientation
- Interplay between orthotropic plies



D. Warren "Advanced Design, Analysis and Optimization of Composite Structures", Altair ATCx Conference, 2015

What is an optimised fibre architecture?

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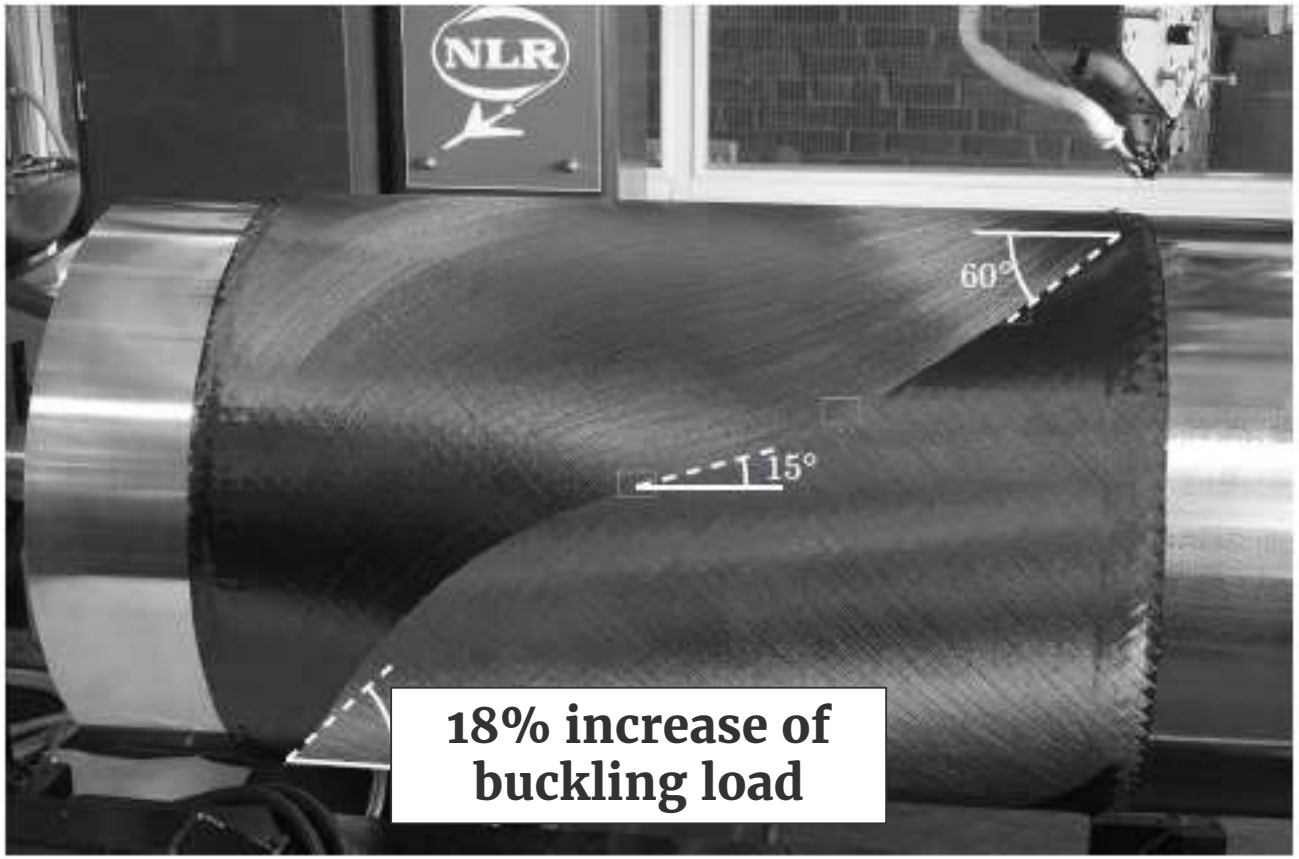
"Modern" optimisation of composite design

- Variable angle tow laminates
- Local load-specific design
- Aeroelastic tailoring

AFP layup of variable-stiffness cylinder



A.W. Blom "Structural performance of fibre placed variable-stiffness composite conical and cylindrical shells", PhD thesis, TU Delft, 2010

What is an optimised fibre architecture?

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"Modern" optimisation of composite design

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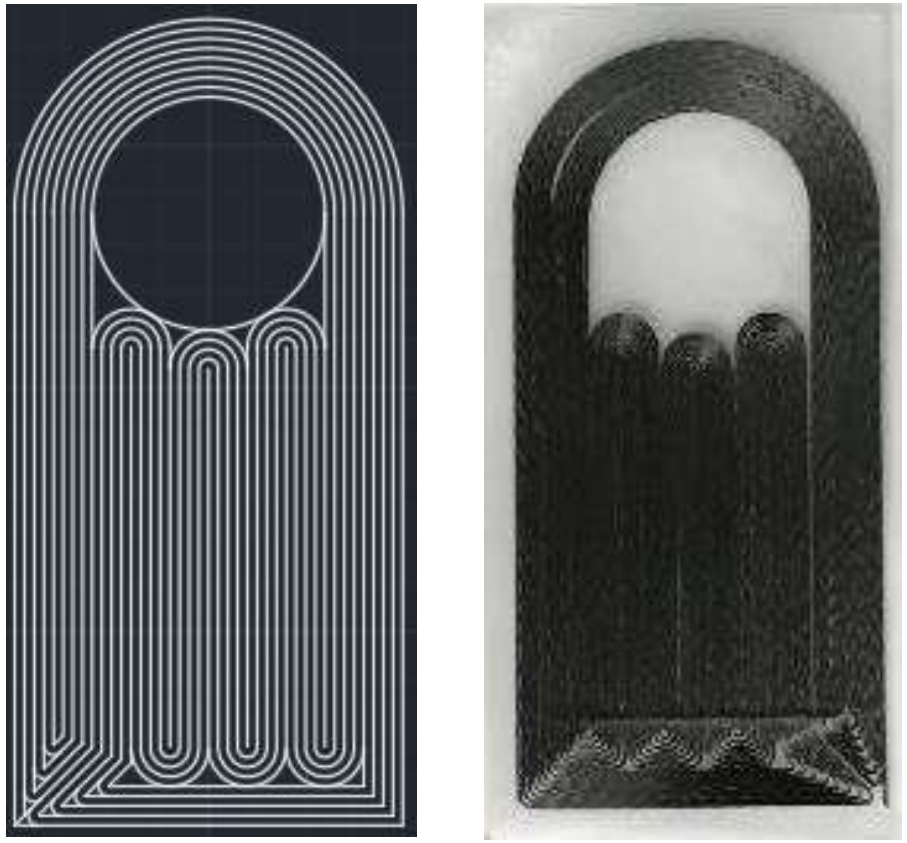
Fibre tailoring in lug joint using composite 3D printing



Courtesy of Peng Zhuo (University of Nottingham)

Optimised textile architectures?

3D weaves, 3D braids

- Resistance to delamination
- Near-net shapes for reduced manufacturing and materials costs
- Integral joints: T joints, PI joints, seamless tubular/box sections
- Possibility to incorporate multifunctional materials

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3D woven composites offer better delamination resistance

Unidirectional non-crimp fabric laminate

Angle interlock 3D woven composite

Optimisation framework for 3D woven textiles

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Optimisation framework for 3D woven textiles

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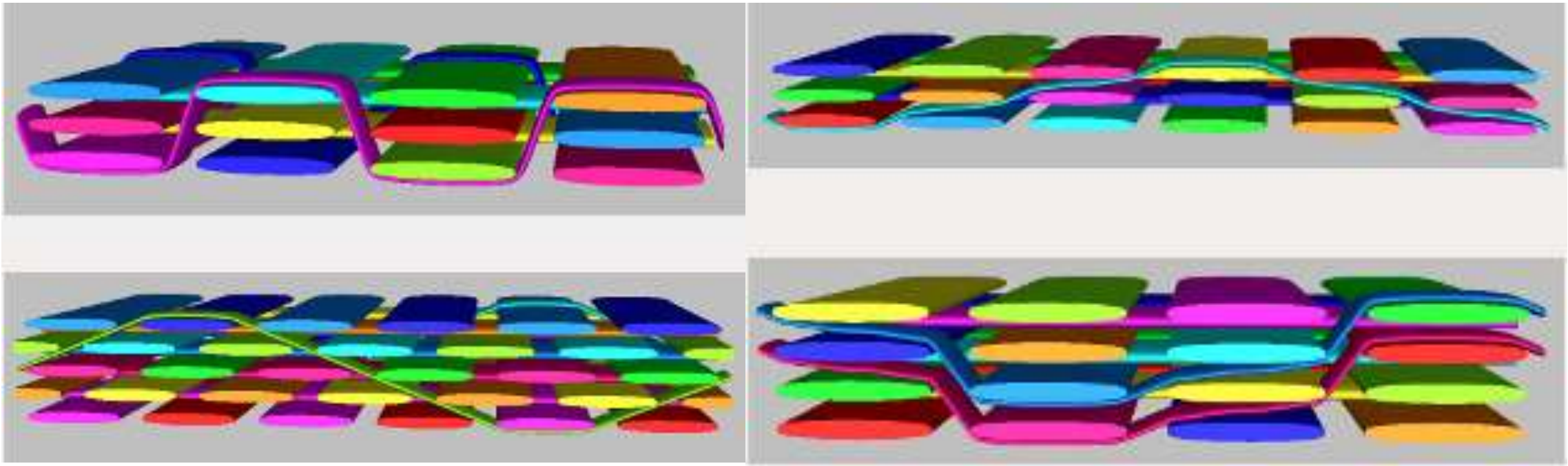
What binder architecture can provide the properties we need?



Optimisation framework for 3D woven textiles

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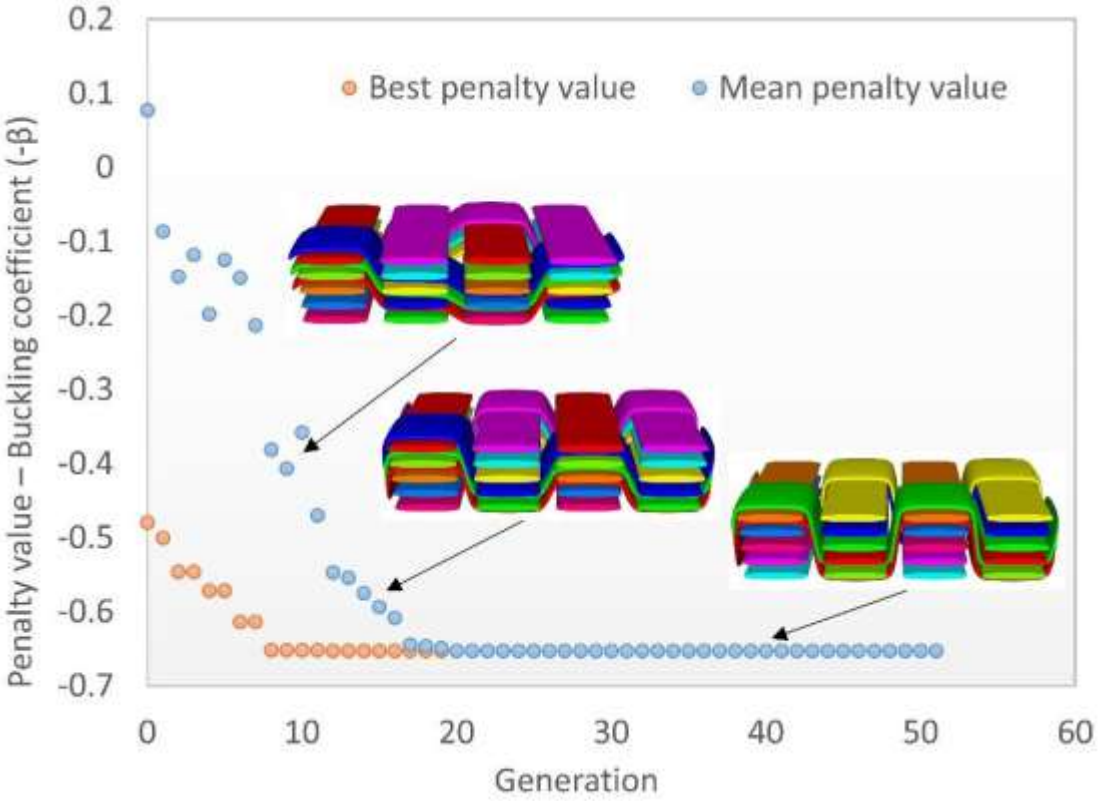
CIMComp Fellowship – establishing the framework

- Impossible to run through all the possible architectures
- Genetic algorithm provides faster way

Manufacturable textiles only



Optimisation framework for 3D woven textiles

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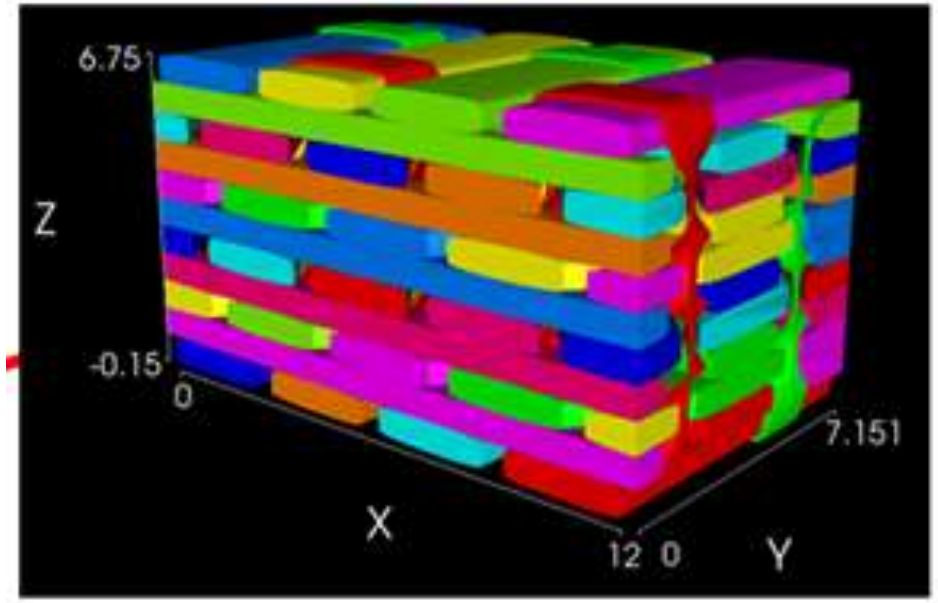
CIMComp feasibility studies – extending the framework

- Relaxing the manufacturing constraints
- Introducing off-axis yarns
- 20% increase of buckling load vs orthogonal 3D weave



Optimisation framework for 3D woven and braided textiles

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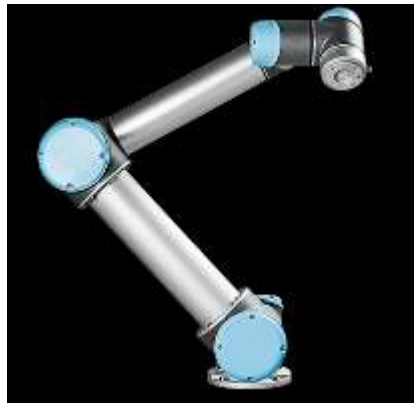
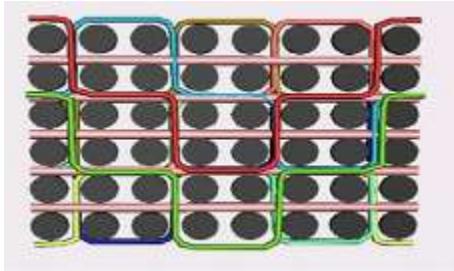
- Relaxing the manufacturing constraints **further**
  - **Significant modifications to state-of-the-art manufacturing technologies**
  - **Development of novel manufacturing concepts driven by optimisation**





  - Programmable motions with the knowledge of textiles to create optimised fibre architectures
- Multi-objective optimisation: buckling, delamination, permeability…

New manufacturing technologies

3D weaving, 3D braiding and many more

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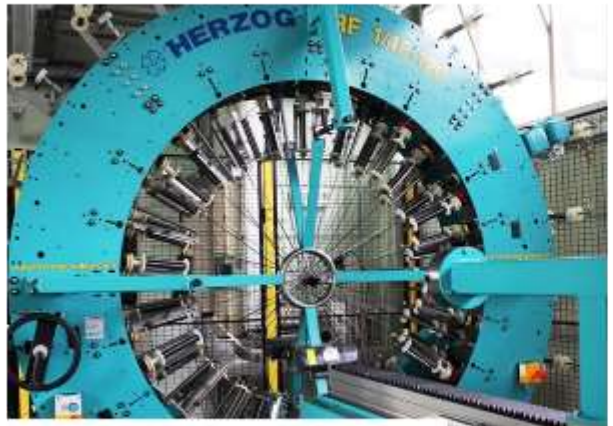
Current toolbox of manufacturing technologies (CIMCOMP)

3d weaving using Jacquard

Robotic tow placement and stitching



Radial braiding

9-axis winding

3D winding

3D Weaving

3D Weaving on a 4 x 4 shuttle loom (1990s)

Carbon fibre weaving on a rapier loom (2014)

Multi-insertion 3D weaving (2015)

Relaxing manufacturing constraints in 3D weaving

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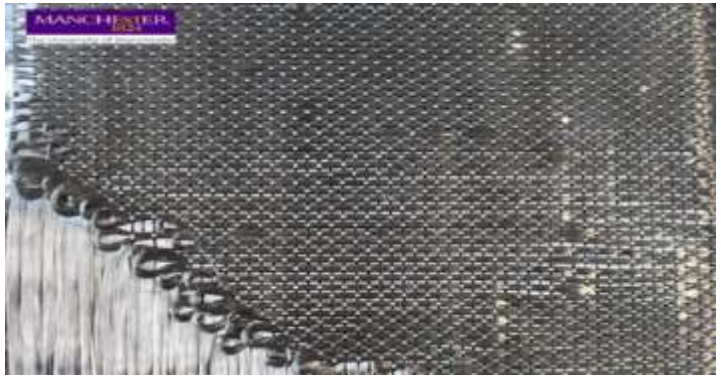
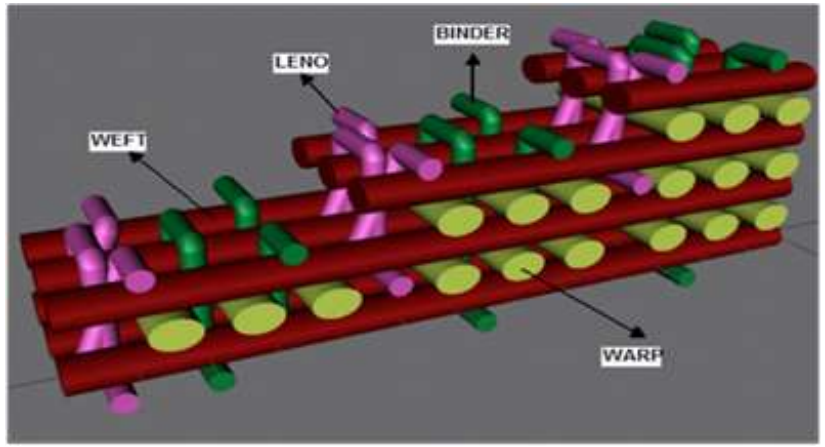
- Ability to change 'weave topology' at any location different locations
- Variable warp, weft and binder densities and tow counts
- Ply drops in warp and weft directions
- Ability to 'lock-and-trim' tows at any location
- Ability to change local tow tensions





Robotic fibre placement with stitching and tufting

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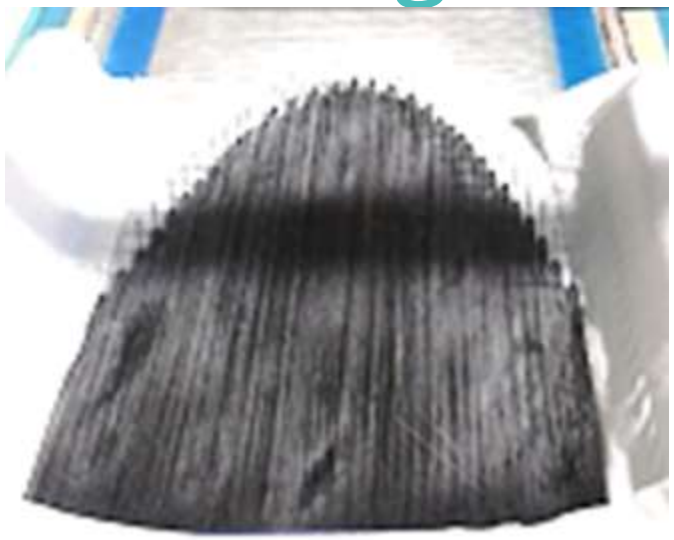
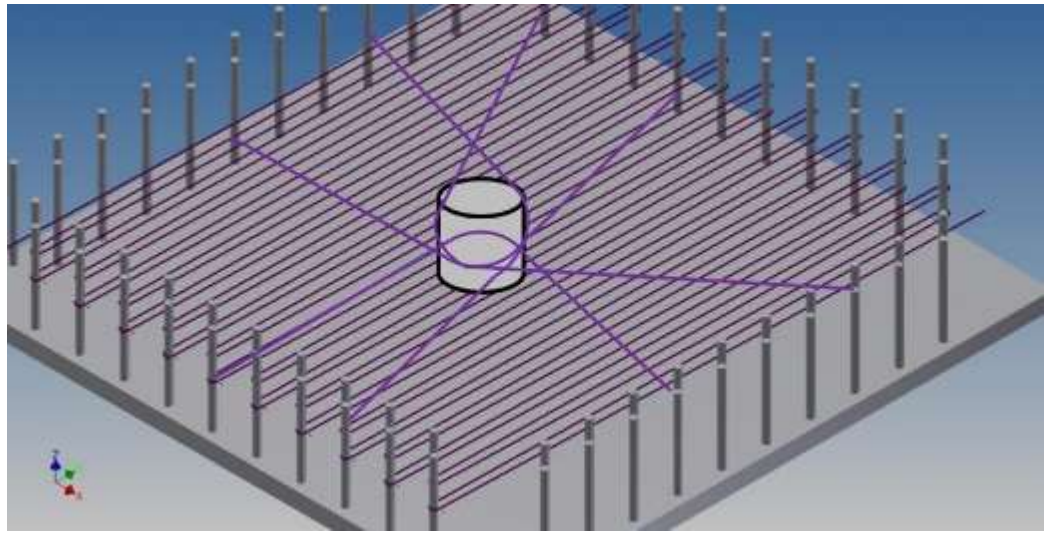


Multi-axial tow placement
Variable density
Contoured plies
Off-axis plies
Local tow steering!



Robotic multi-axial 3D weaving

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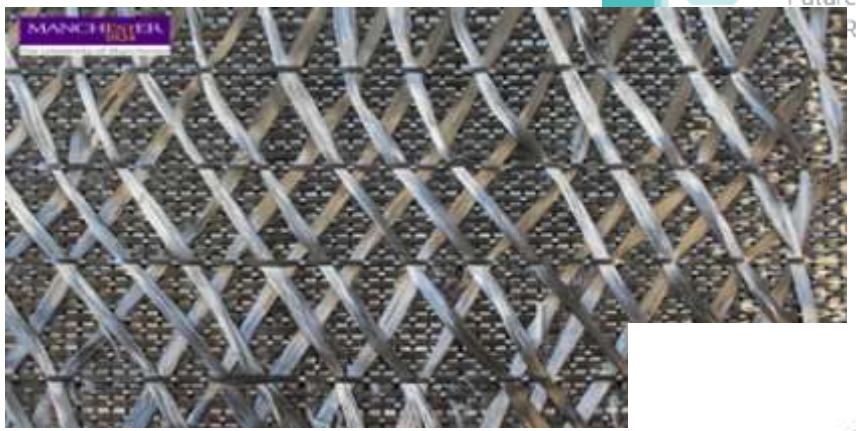
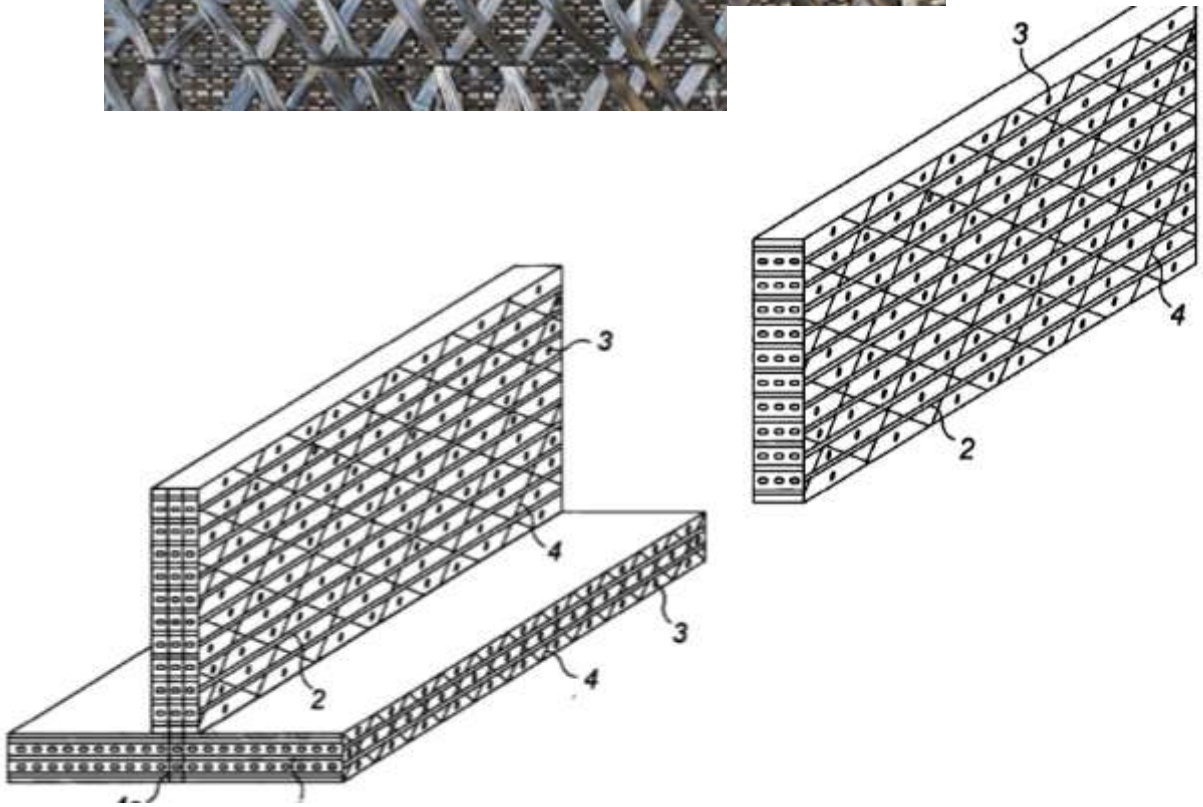
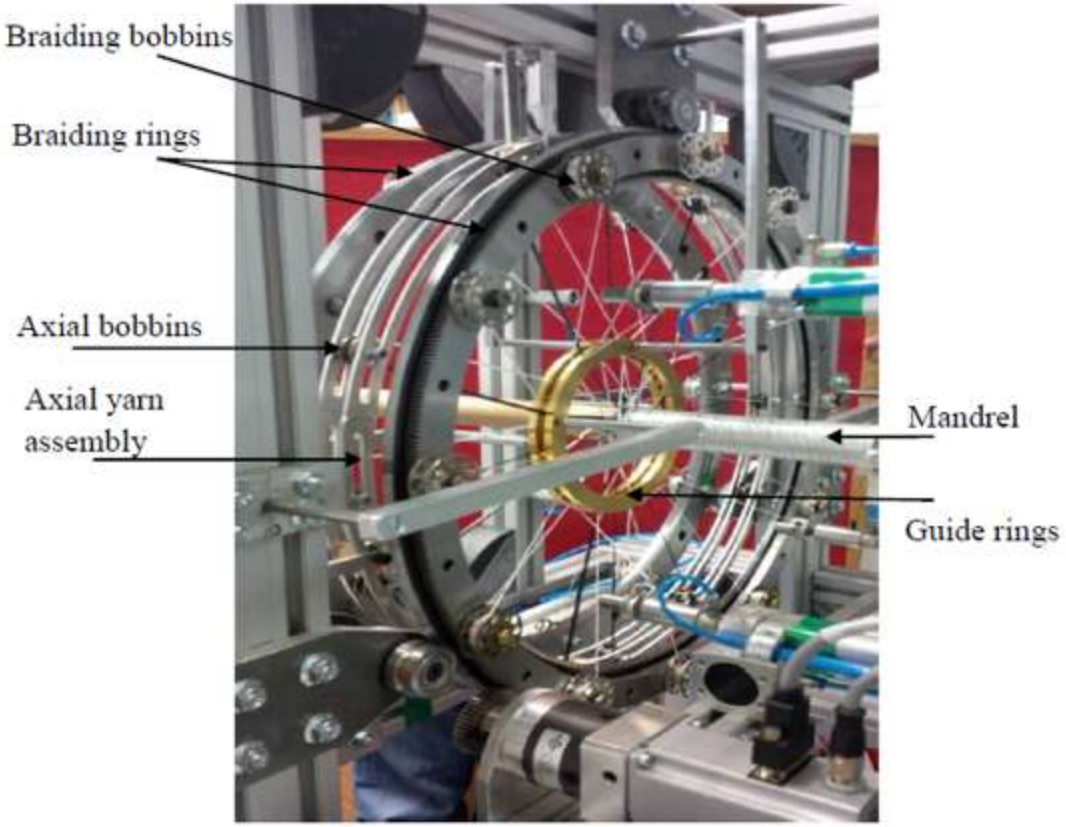
Off-axis tows
Tow-steering
Plydrops
Integral joints

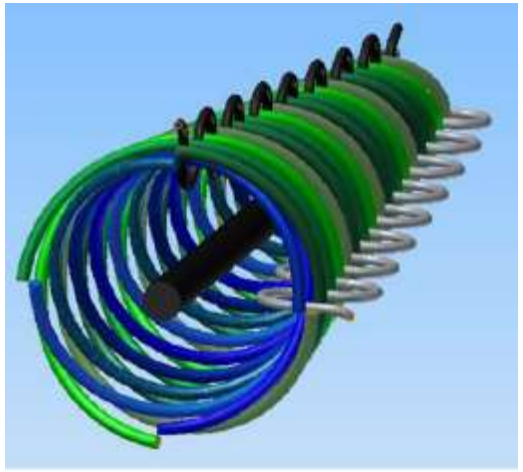




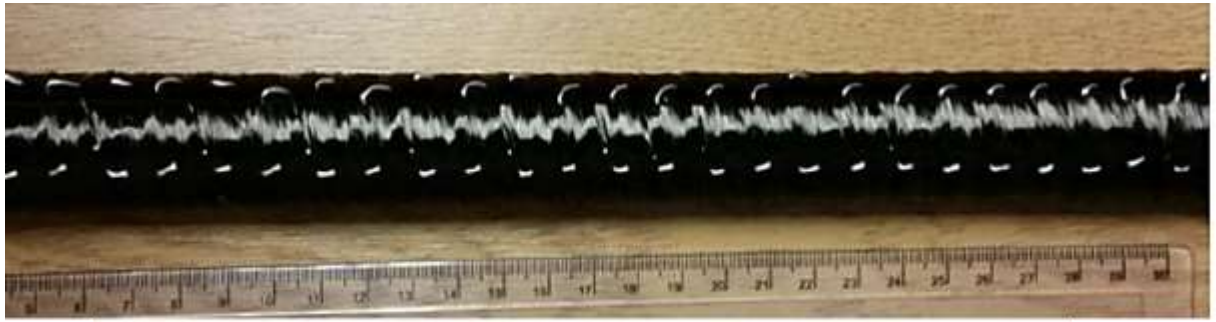
3D braiding

Triaxial or quadraxial layup
Steering of +/- tows in each layer
Through-thickness binders





Orthogonal braided structure (CT images)



Tubular multilayer braided preform with z binders

Discussion

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Potential routes for manufacturing optimised preforms

- 3D printing with continuous tows
- AFP technologies with prepregs and dry tape
- Textile preforming with ‘commercial tows’

  3D weaving and braiding technologies with optimized fibre layups, containing through-thickness reinforcement

  Low-cost, high volume manufacturing

  Compatibility with liquid infusion tech

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