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Design Process for 4D printed moisture actuated flax fibre reinforced polylactic acid composites.

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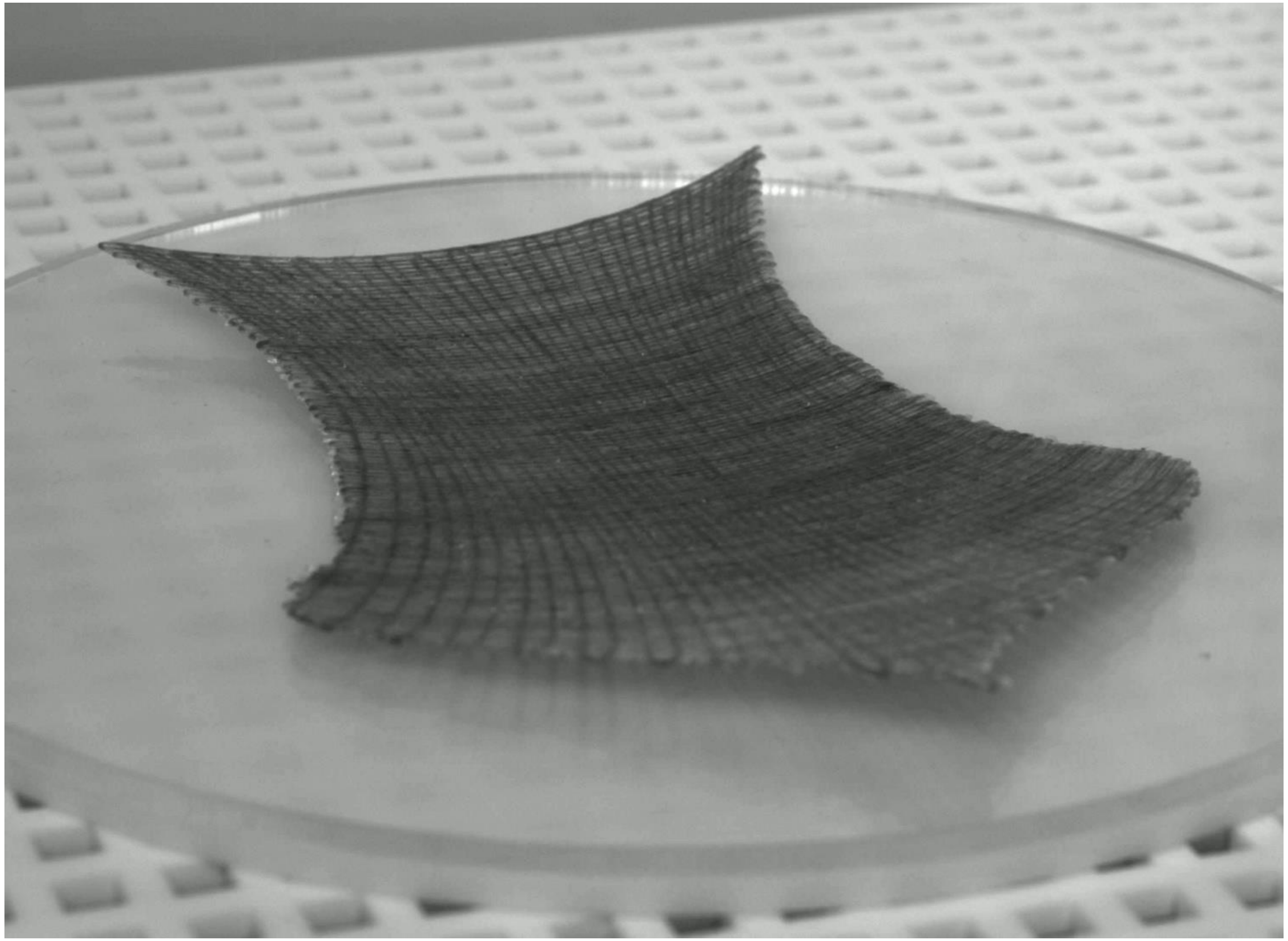
4D printing



de Kergariou, et al.. The design of 4D printed hygromorphs: state-of-the-art and future challenges. Advanced Functional Materials, 33, p2210353, 2023.

4D printing continuous flax fibre composite

Measure the porosity:

de Kergariou, C., Le Duigou, A., Popineau, V., Gager, V., Kervoelen, A., Perriman, A., Saidani-Scott, H., Allegri, G., Panzera, T.H. and Scarpa, F., 2021. Measure of porosity in flax fibres reinforced polylactic acid biocomposites. Composites Part A: Applied Science and Manufacturing, 141, p.106183.

Influence of humidity on stiffness:

de Kergariou, C., Saidani-Scott, H., Perriman, A., Scarpa, F. and Le Duigou, A., 2022. The influence of the humidity on the mechanical properties of 3D printed continuous flax fibre reinforced poly (lactic acid) composites. Composites Part A: Applied Science and Manufacturing, 155, p.106805.

Definition 4D printing:

de Kergariou, Charles, Demoly, Frédéric, Perriman, Adam, Le Duigou, Antoine, and Scarpa, Fabrizio, 2023. The design of 4D printed hygromorphs: state-of-the-art and future challenges. Advanced Functional Materials, 33, p2210353.

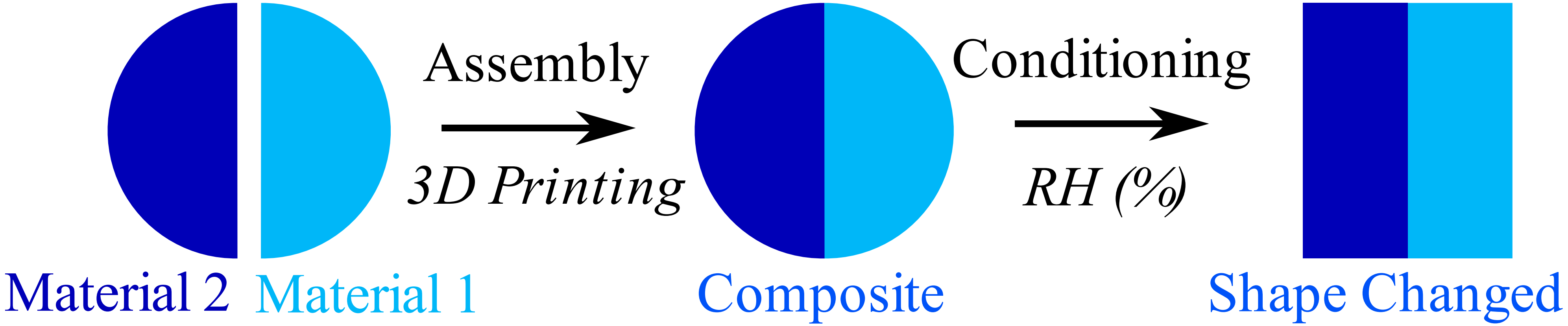
Design of 4D printed hygromorphs:

de Kergariou, Charles and Kim, Byung Chul and Perriman, Adam and Le Duigou, Antoine and Guessasma, Sofiane and Scarpa, Fabrizio, 2022. Design of 3D and 4D printed continuous fibre composites via an evolutionary algorithm and voxel-based Finite Elements: Application to natural fibre hygromorphs. Additive Manufacturing, volume 59, 11 p.103144.

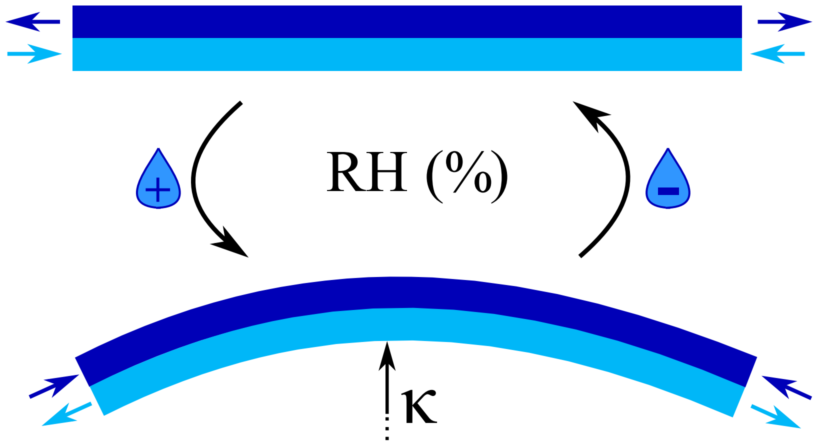
de Kergariou, Charles, Perriman, Adam, Le Duigou, Antoine, and Scarpa, Fabrizio, 2022. Design space and manufacturing of programmable 4D printed continuous flax fibre polylactic acid composite hygromorphs. Materials and Design, volume 225, page 111472.

4D printing

Production:



Actuation:



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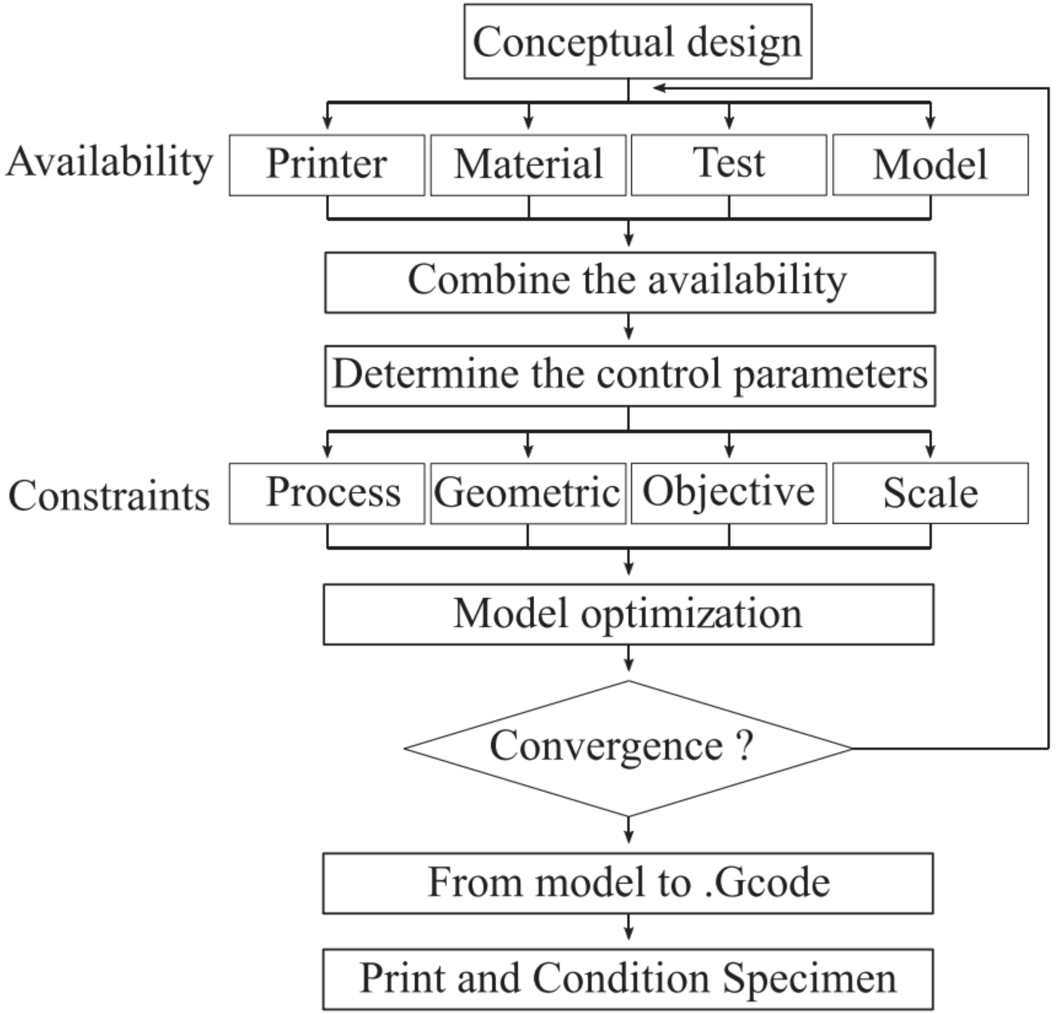
Conclusion



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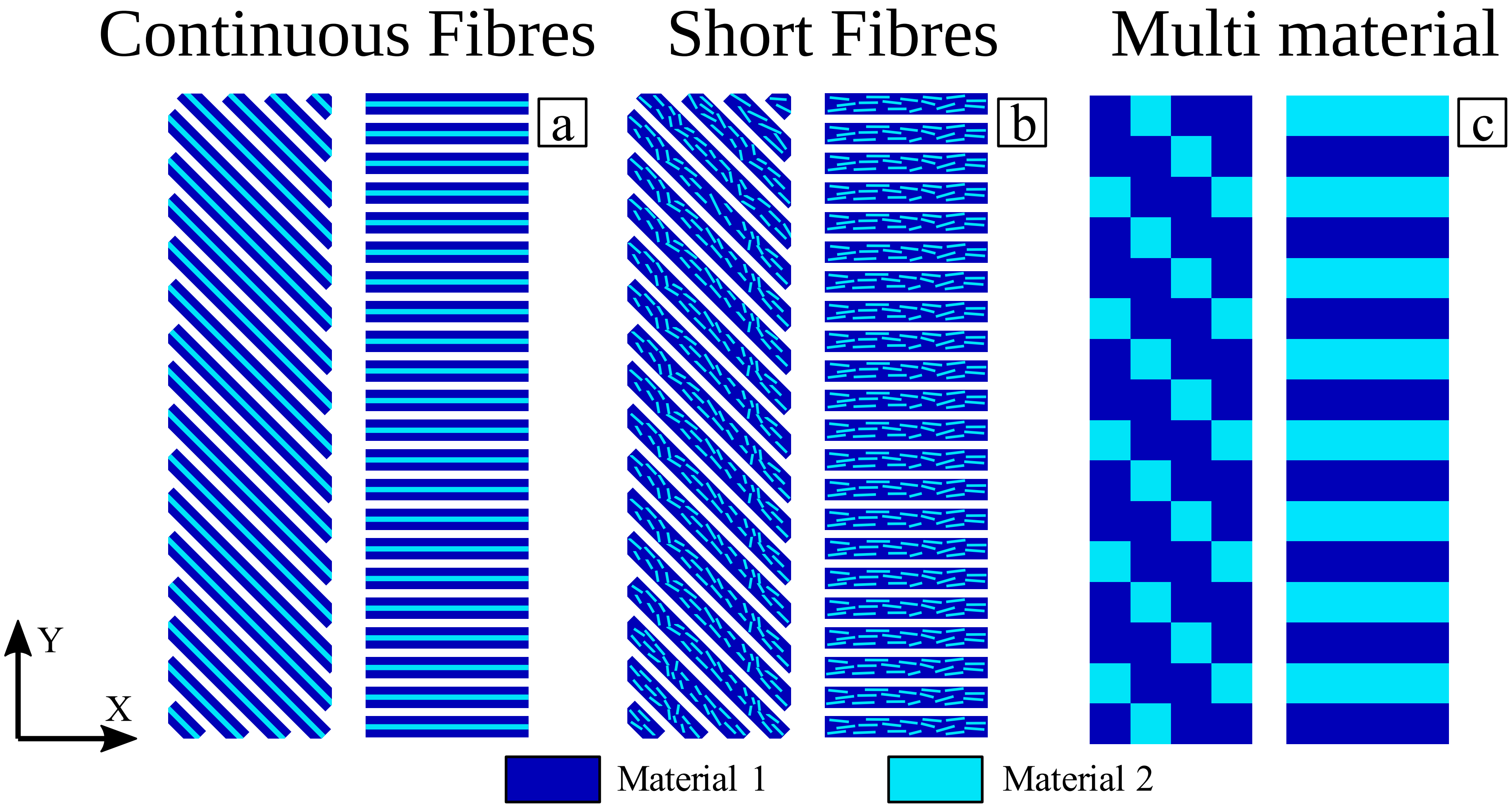
Type of actuator



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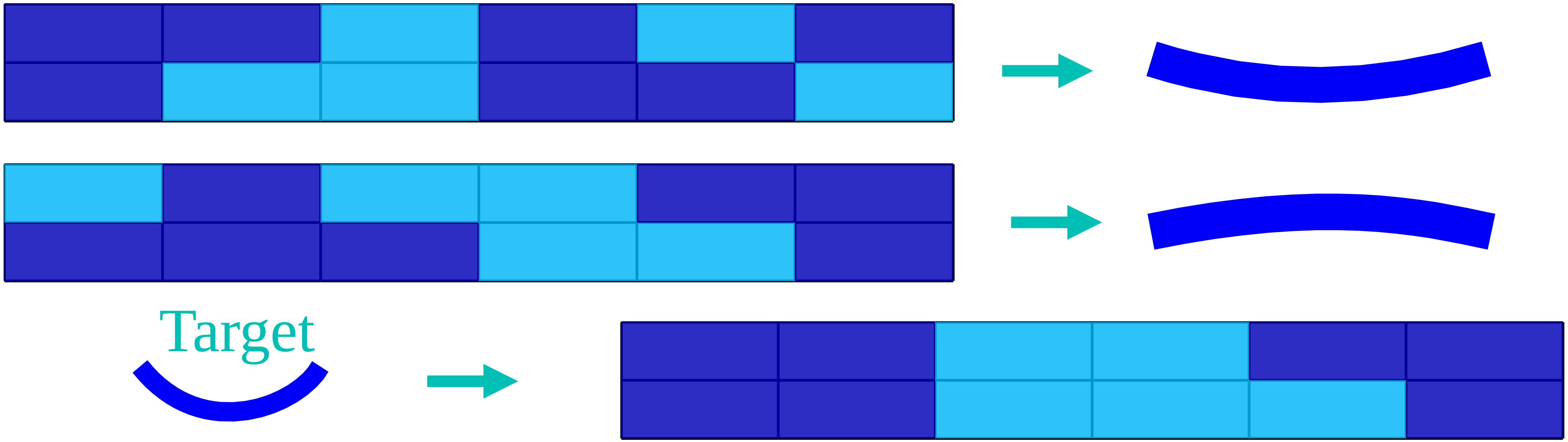
Optimisation

Material distribution:



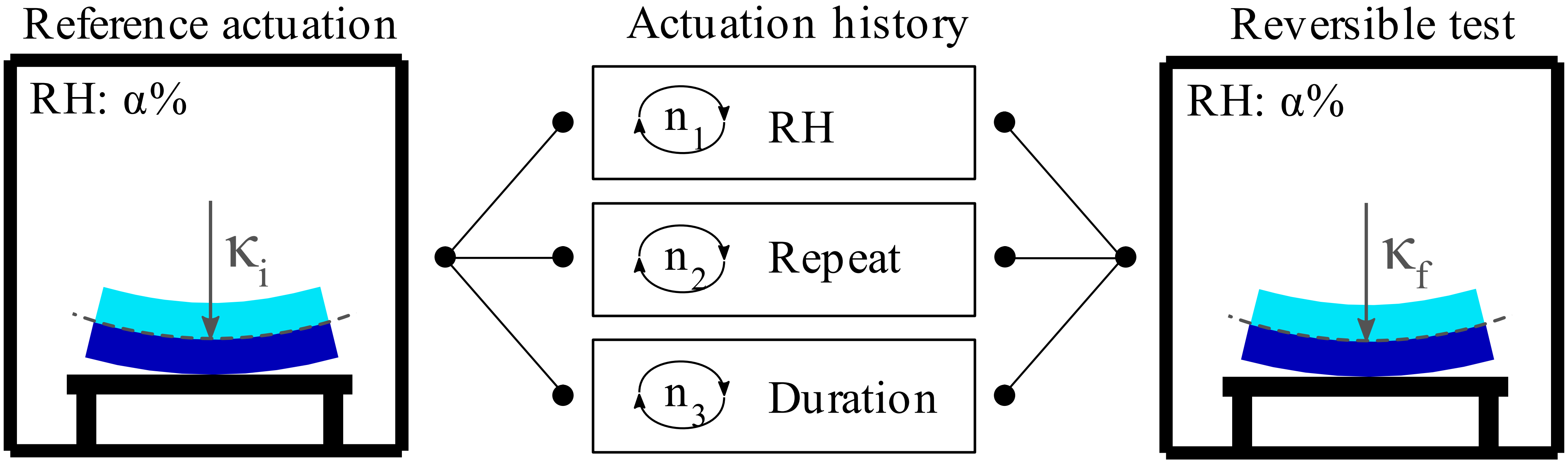
Evolutionary Algorithms

Neural Networks

Optimised geometry to 4D Printing

de Kergariou, et al.. The design of 4D printed hygromorphs: state-of-the-art and future challenges. Advanced Functional Materials, 33, p2210353, 2023.

Reversibility



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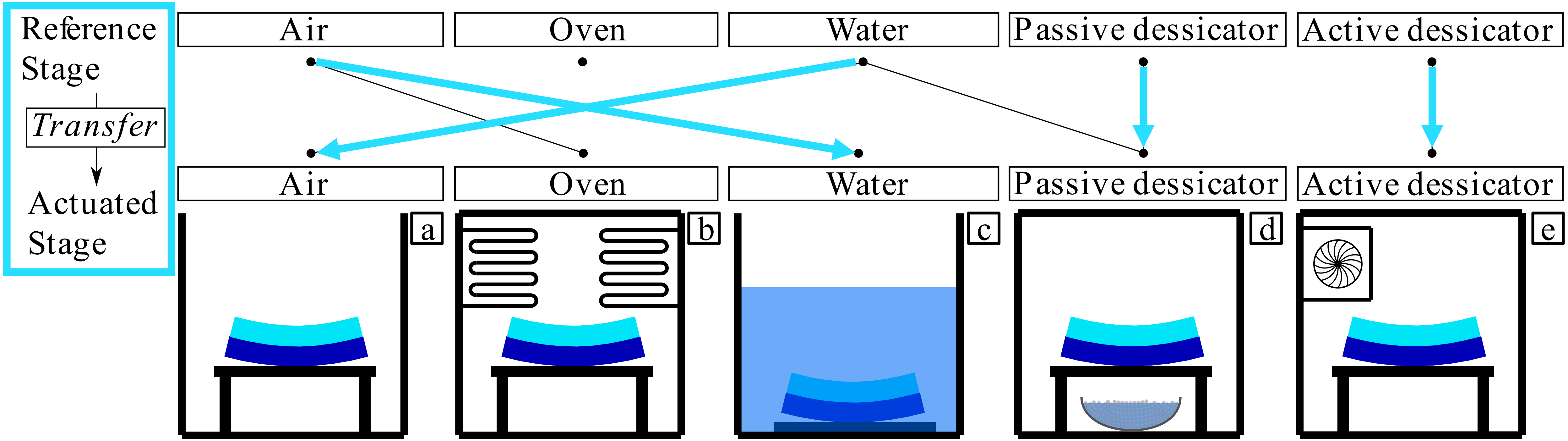
Conditioning



Actuation Measurement

Physical

Photos

Point of Interest

de Kergariou, et al.. The design of 4D printed hygromorphs: state-of-the-art and future challenges. Advanced Functional Materials, 33, p2210353, 2023.

What you can find in the paper:

1- Need to **design** an hygromorph

2- **Optimise** model of 4D printed actuators

3- **Produce** 4D printed hygromorph

4- **Measure properties** influencing the actuation of hygomorph

5- Conduct **actuation test**

6- Run r**eversibility** test

7- Measure **speed of actuation**

de Kergariou, et al.. The design of 4D printed hygromorphs: state-of-the-art and future challenges. Advanced Functional Materials, 33, p2210353, 2023.

Conclusion

1- Classify the different types of studies for 4D printed structures.

2- Defined different categories of materials used to create the 4D printed humidity triggered bending actuators.

3- Characterise the different techniques to condition specimens and measure actuation.

4- Initiate standardization work for different elements of the research field: reversibility, speed, actuation measure, deformation tests.

5- Discussed and compared the different modelling and geometry optimisation techniques as well as the measurement of the properties needed for the model.

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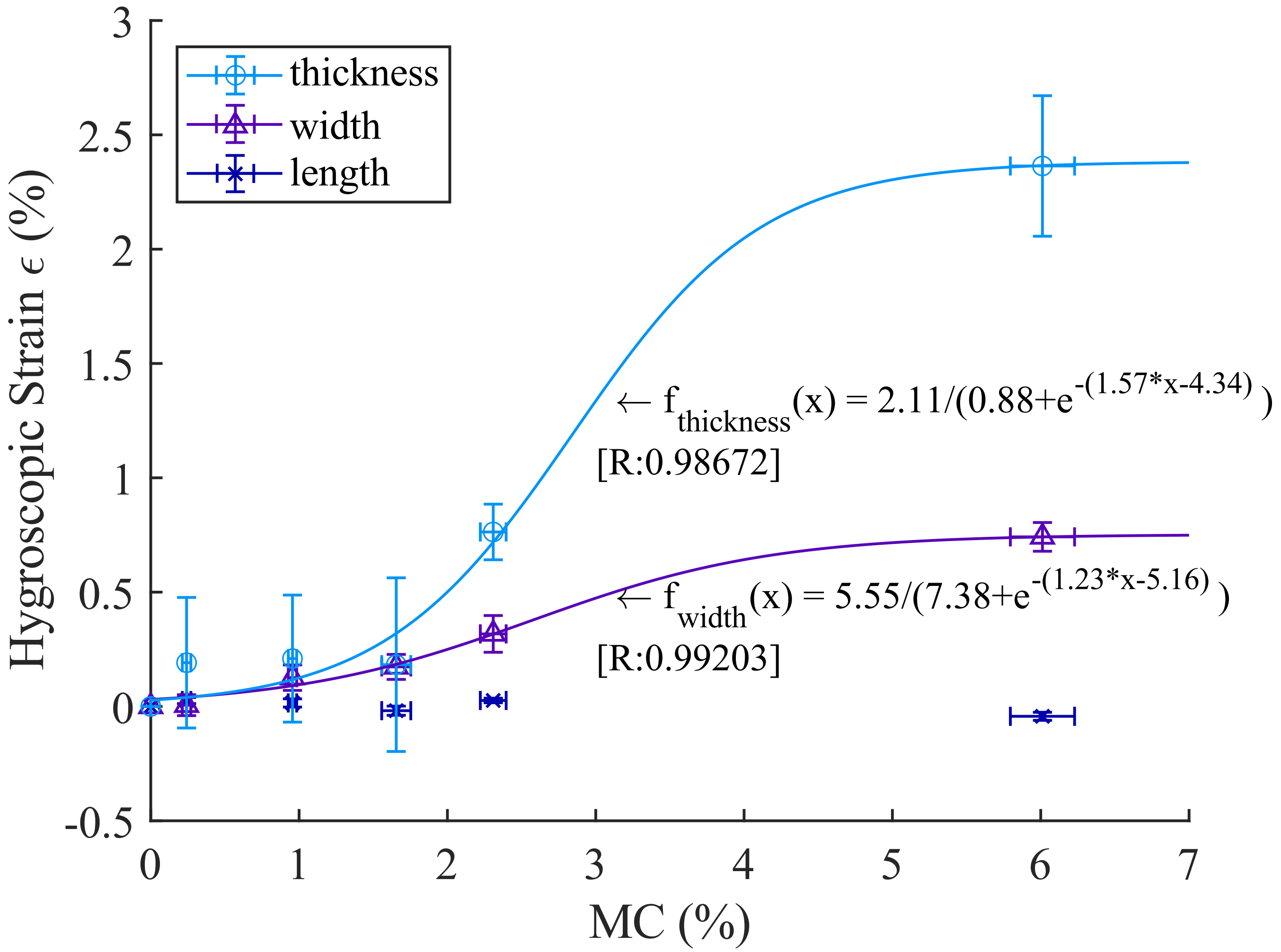
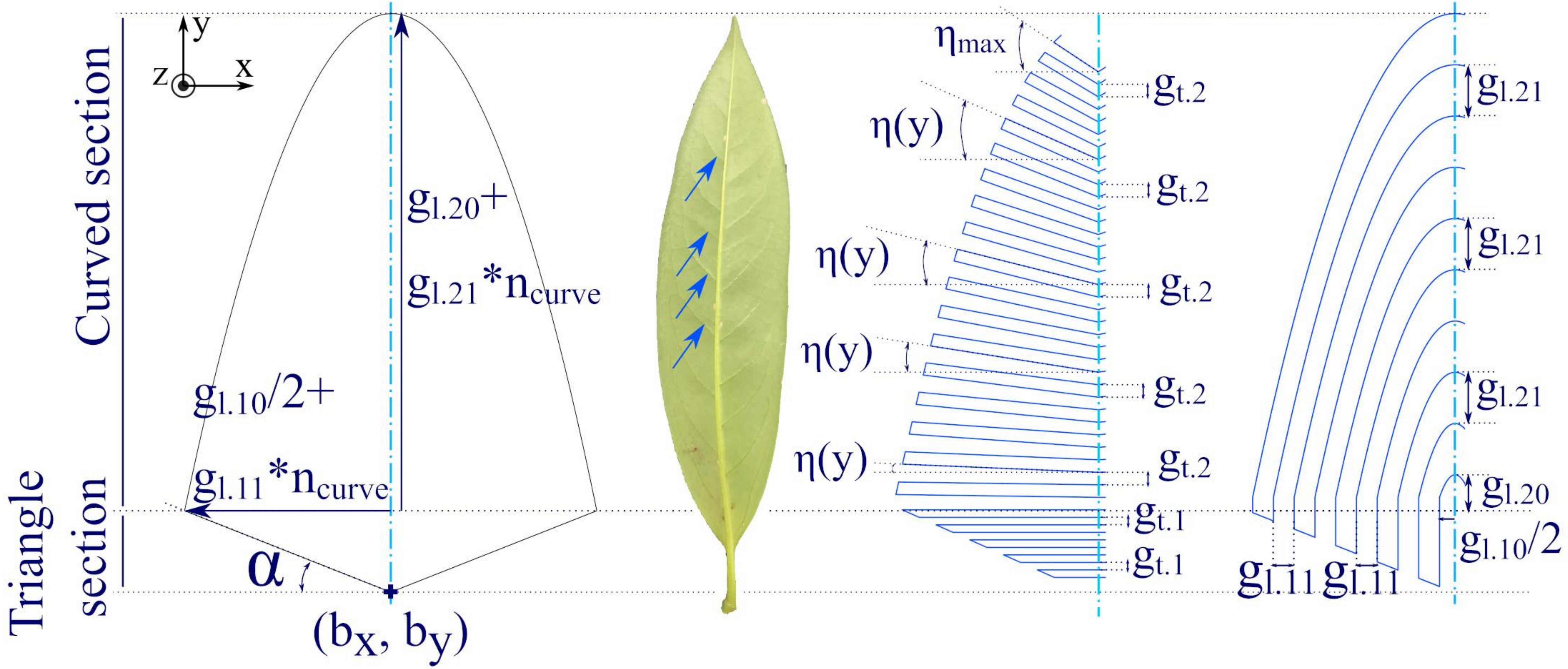
Measuring the hygroscopic effect



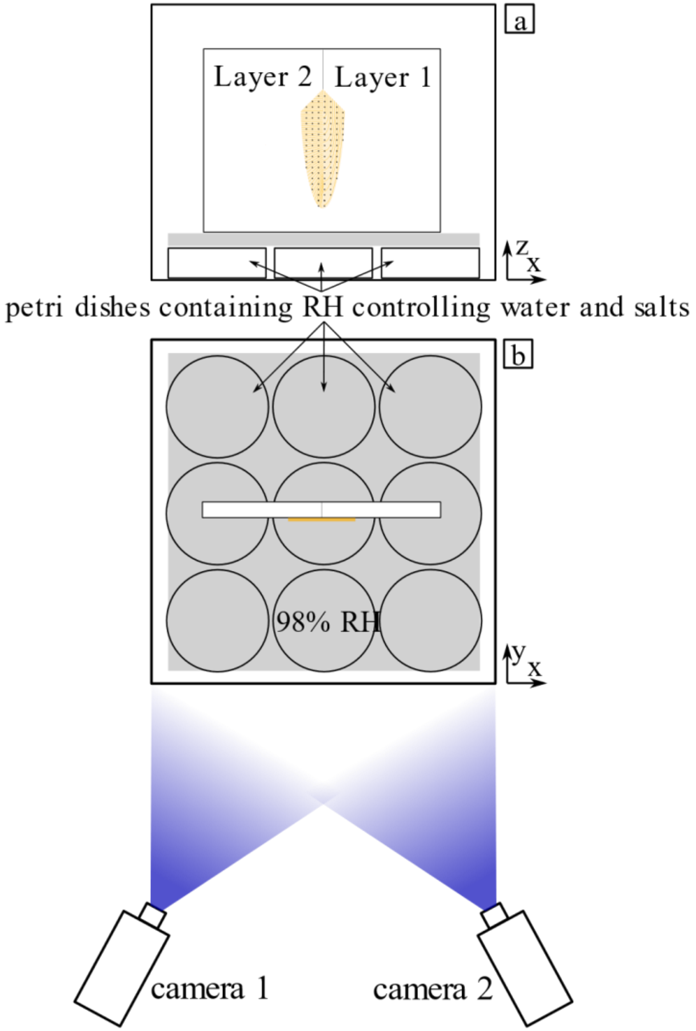
C. de Kergariou, et al. Design of 3D and 4D printed continuous fibre composites via an evolutionary algorithm and voxel-based Finite Elements: Application to natural fibre hygromorphs. Additive Manufacturing, volume 59, 11 p.103144 2022.

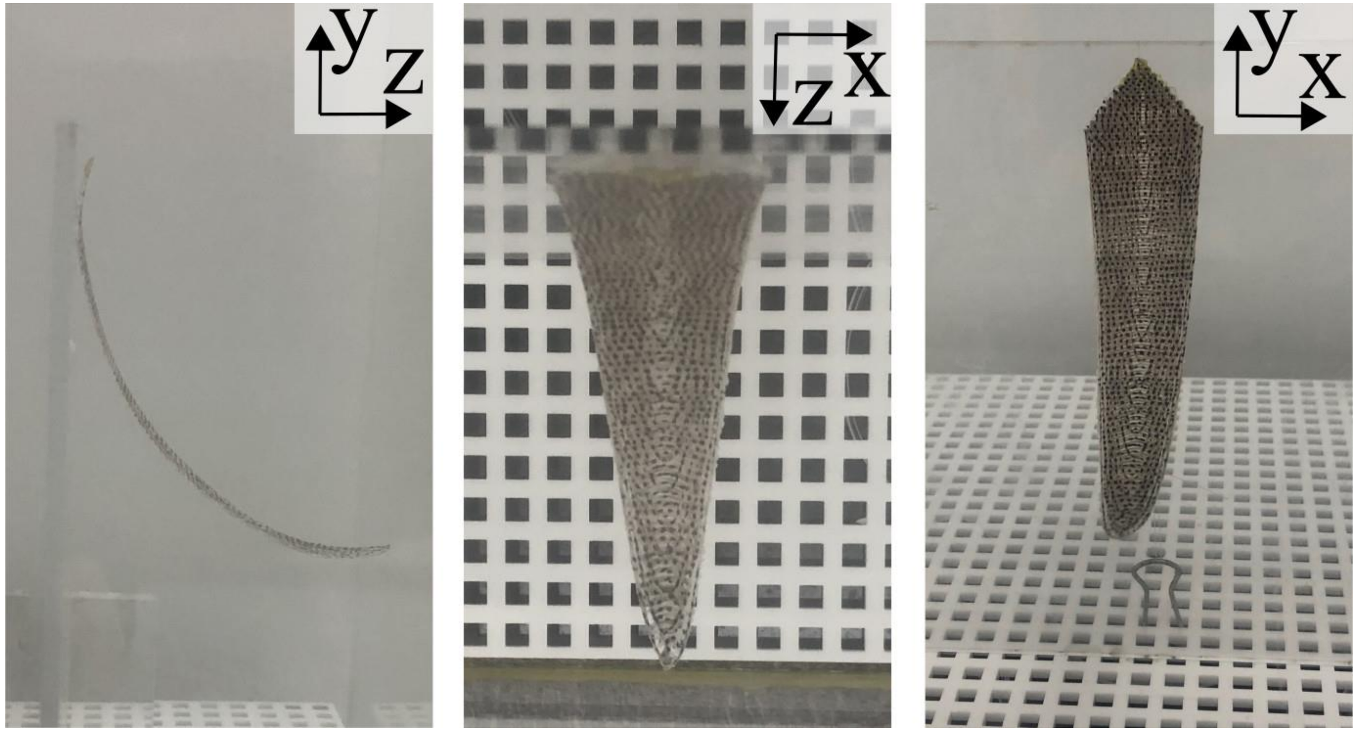
Printed structure



C. de Kergariou, et al. *Design of 3D and 4D printed continuous fibre composites via an evolutionary algorithm and voxel-based Finite Elements: Application to natural fibre hygromorphs. Additive Manufacturing, volume 59, 11 p.103144 2022.*

Conditioning





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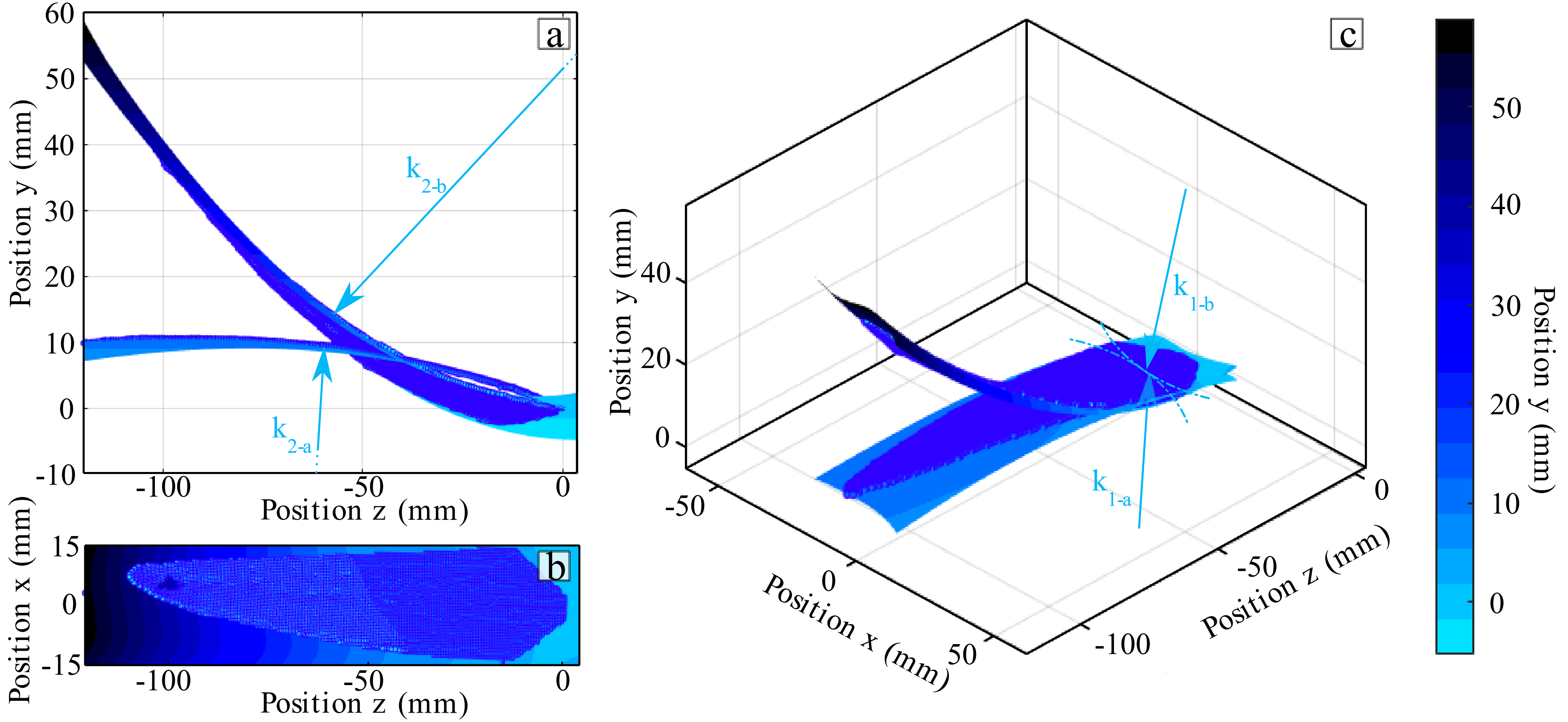
FEA vs Experiment



Good qualitative comparison

Variable deformation

C. de Kergariou, et al. Design of 3D and 4D printed continuous fibre composites via an evolutionary algorithm and voxel-based Finite Elements: Application to natural fibre hygromorphs. Additive Manufacturing, volume 59, 11 p.103144 2022.

What you can find in the paper:

1- **Model** continuous fibre 3D and 4D printed composites

2- **3D DIC test set up** for out-of-water actuation test

3- **Leaf-inspired** printing pattern to obtain synclastic curvature

4- Discuss the influence of **inter-filament distance** on actuation

5- Discuss **variability** in 4D printing actuation measurement

6- Discuss **genetic algorithm** optimisation of printing pattern

C. de Kergariou, et al. Design of 3D and 4D printed continuous fibre composites via an evolutionary algorithm and voxel-based Finite Elements: Application to natural fibre hygromorphs. Additive Manufacturing, volume 59, 11 p.103144 2022.

Conclusion

1- Model to design 3D and 4D printed continuous fibre composite structures

2- Measure the hygro expansion of 3D printed continuous flax fibre reinforced polylactic acid

3- Bioinspired (leaf) structure produced and tested for actuation

4- Define a way to record the deformation via 3D digital image correlation

5- Compare the actuation model to the specimen: good qualitative comparison & highlight of the reasons for the qualitative difference

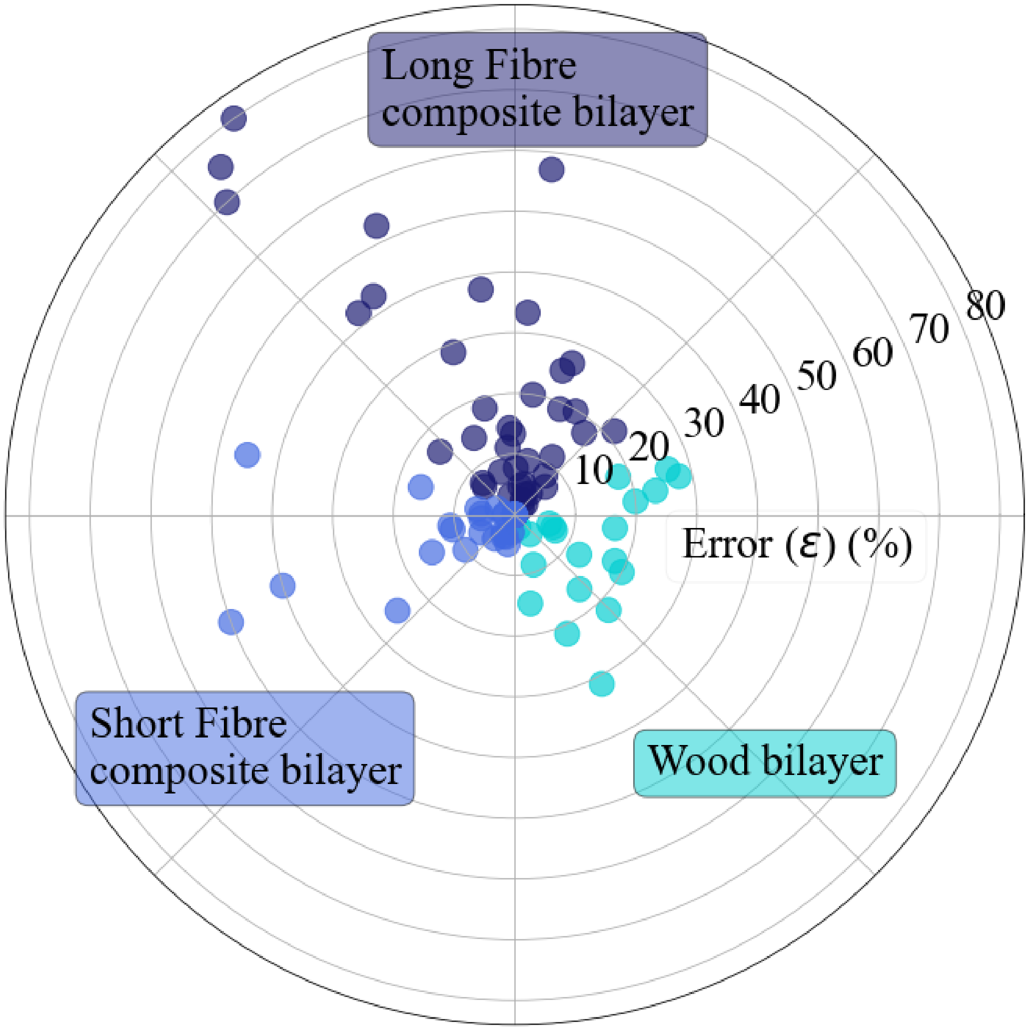
6- We also discuss optimisation of the filament path via Genetic Algorithm

C. de Kergariou, et al. Design of 3D and 4D printed continuous fibre composites via an evolutionary algorithm and voxel-based Finite Elements: Application to natural fibre hygromorphs. Additive Manufacturing, volume 59, 11 p.103144 2022.

FEA vs Timoshenko

Bilayer Curvature Equation Timoshenko:

$$\delta\kappa = f(\delta\beta, \delta MC, t_1, t_2, E_1, E_2)$$



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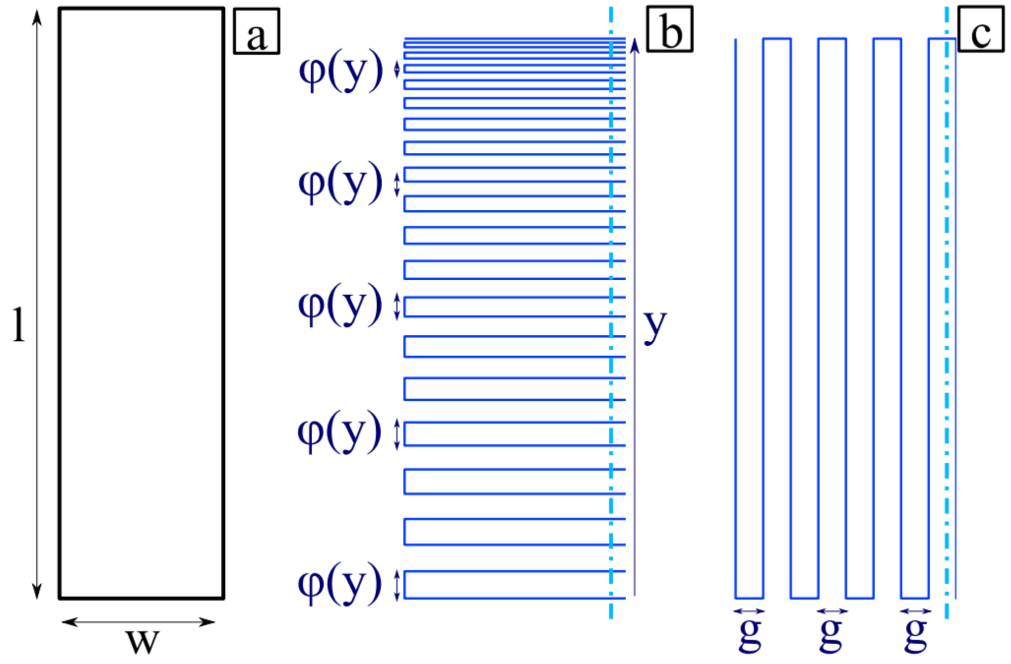
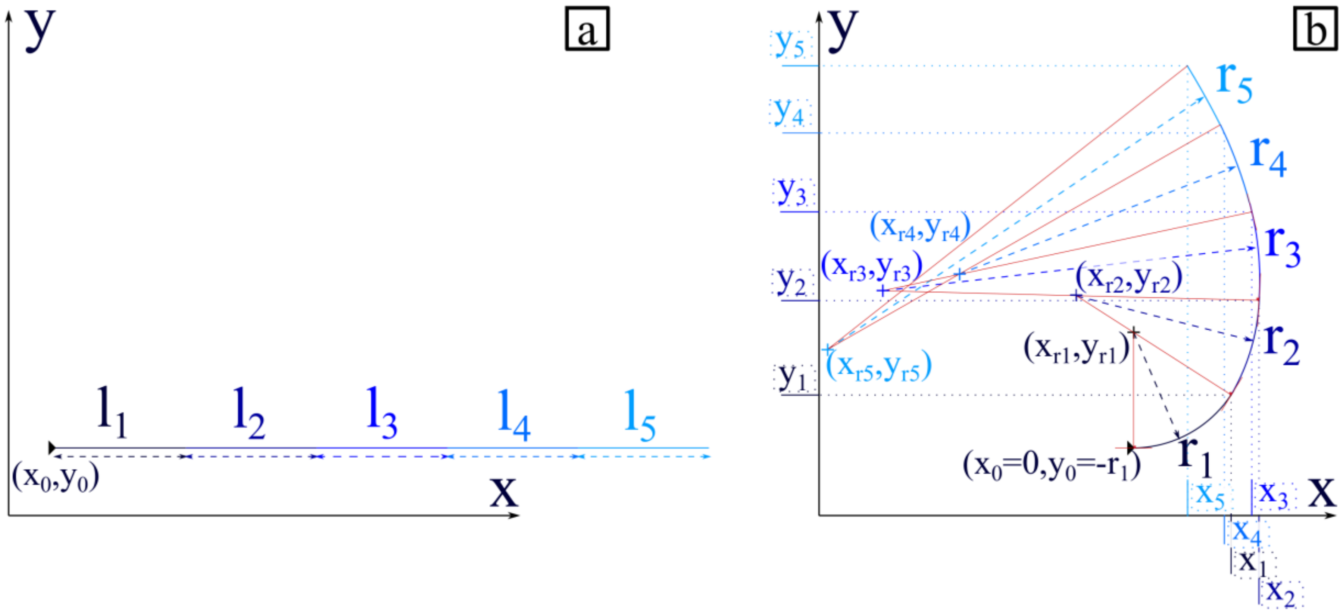
FEA vs Timoshenko

3D printing G-code:



Model:



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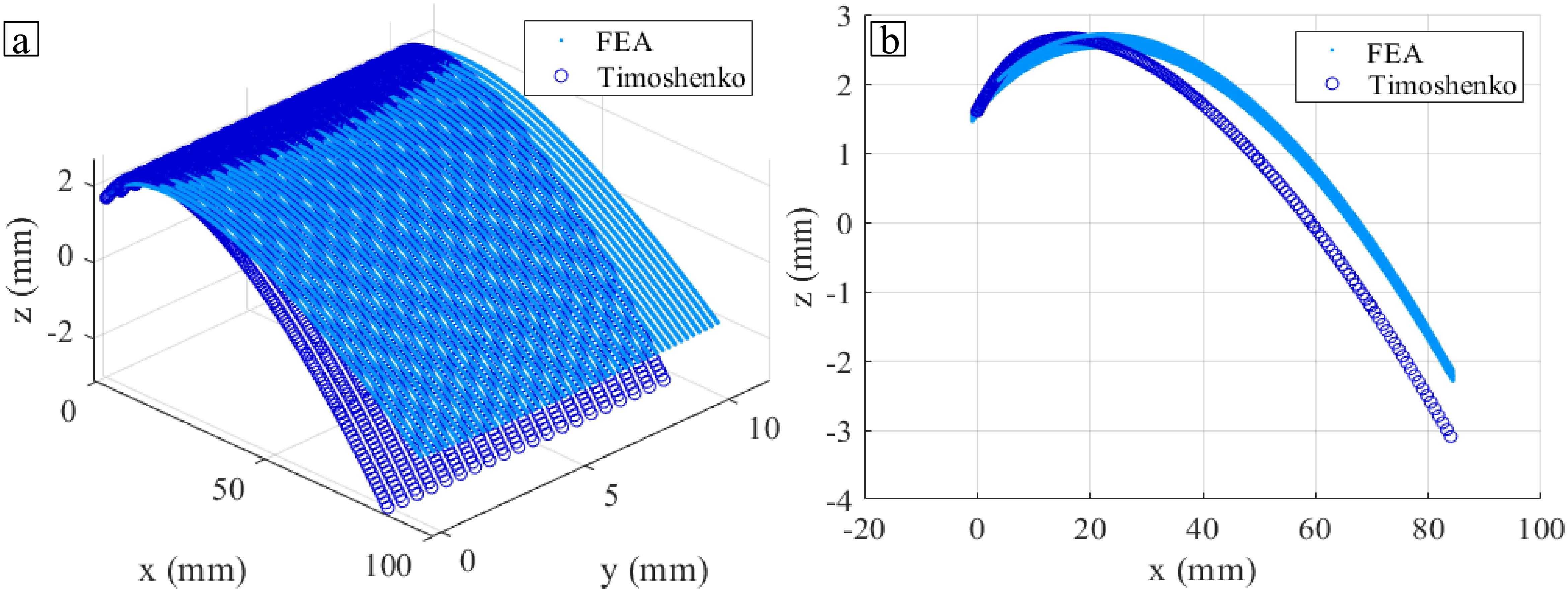
FEA vs Timoshenko



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What you can find in the paper:

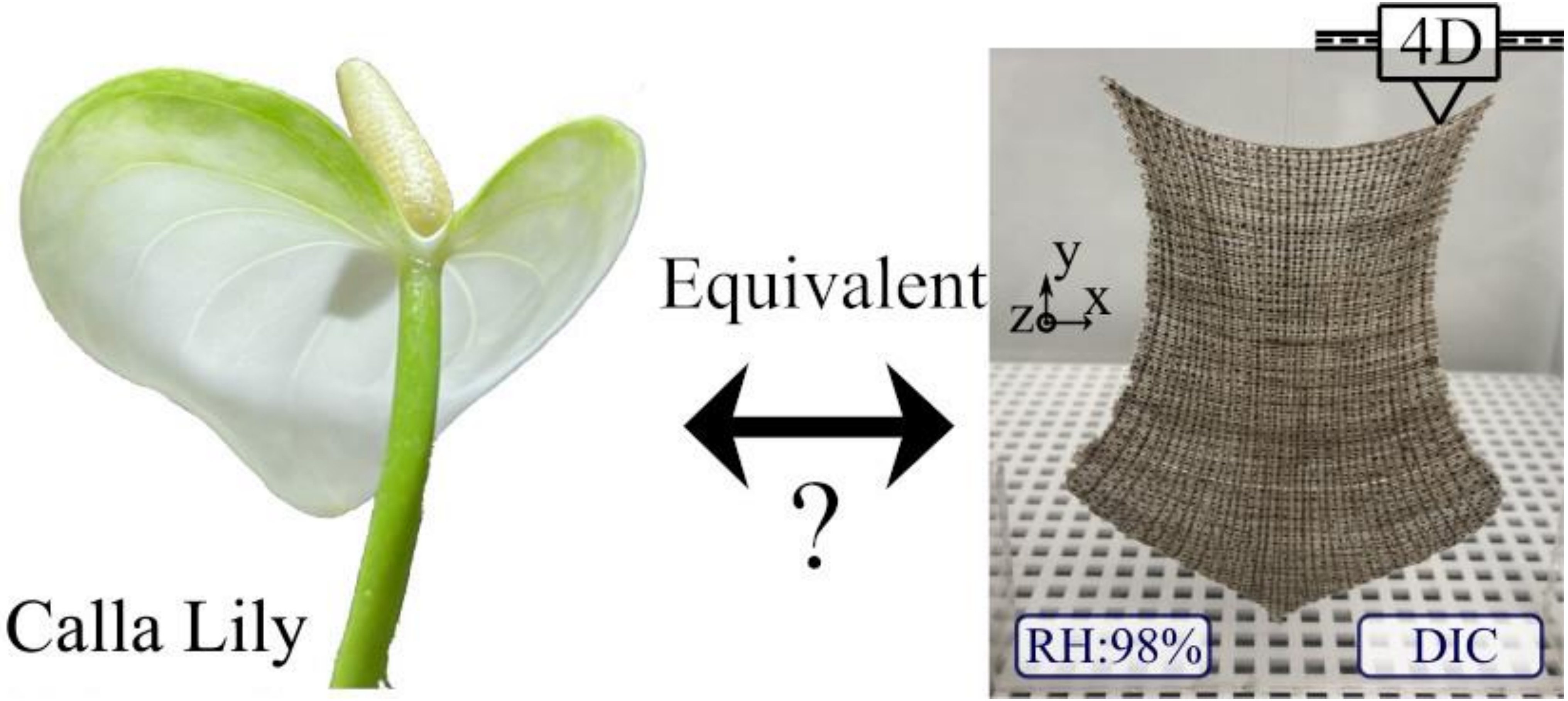
1- Model for varying **inter-filament distance** specimens

2- Create a data base for the **accuracy of the Timoshenko** bilayer beam equation for hygromorph presented in open literature

3- Discuss **validity** of FEA model created

C. de Kergariou, et al. Design of 3D and 4D printed continuous fibre composites via an evolutionary algorithm and voxel-based Finite Elements: Application to natural fibre hygromorphs. Additive Manufacturing, volume 59, 11 p.103144 2022.

Calla Lily



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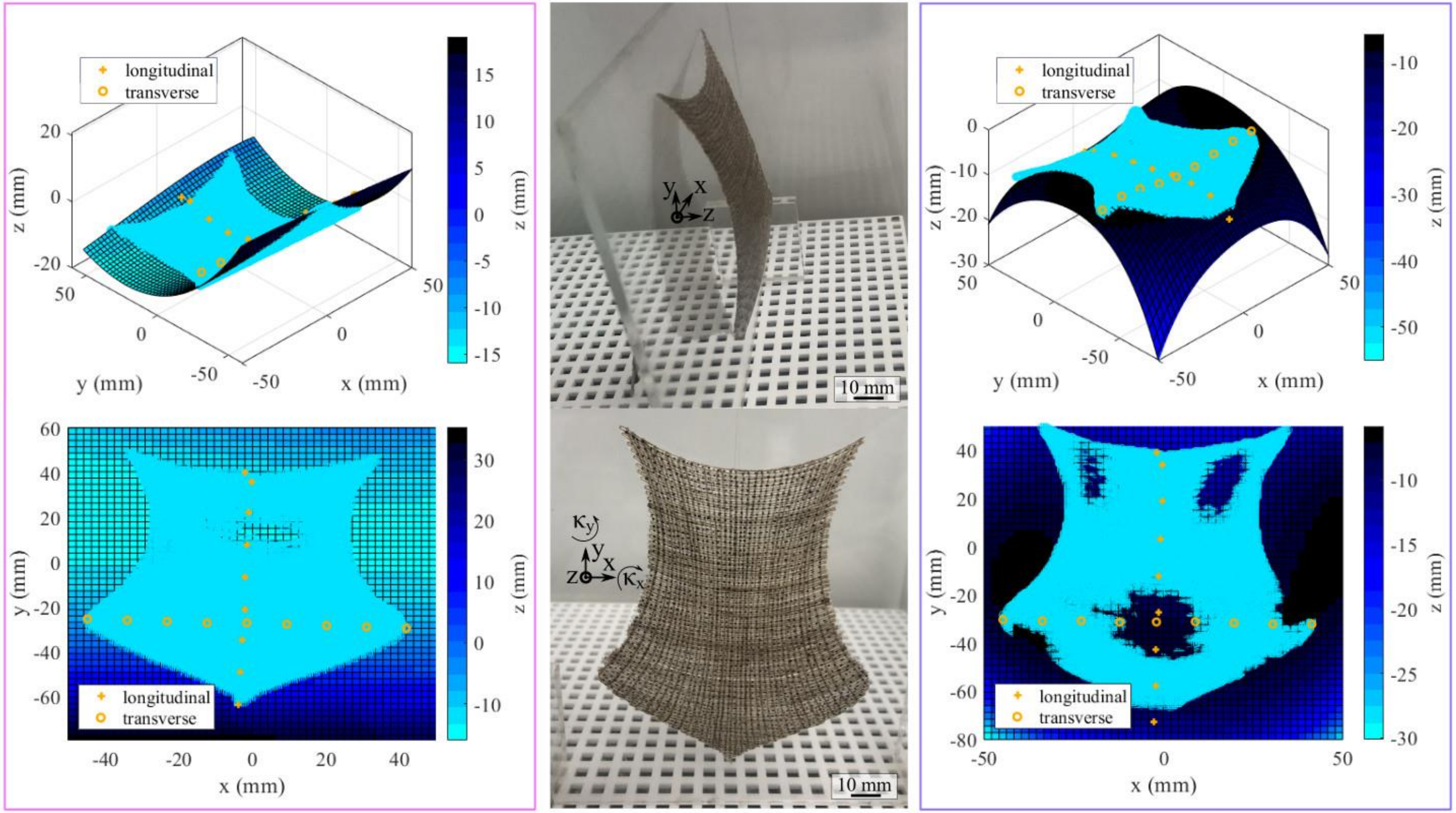
Calla Lily



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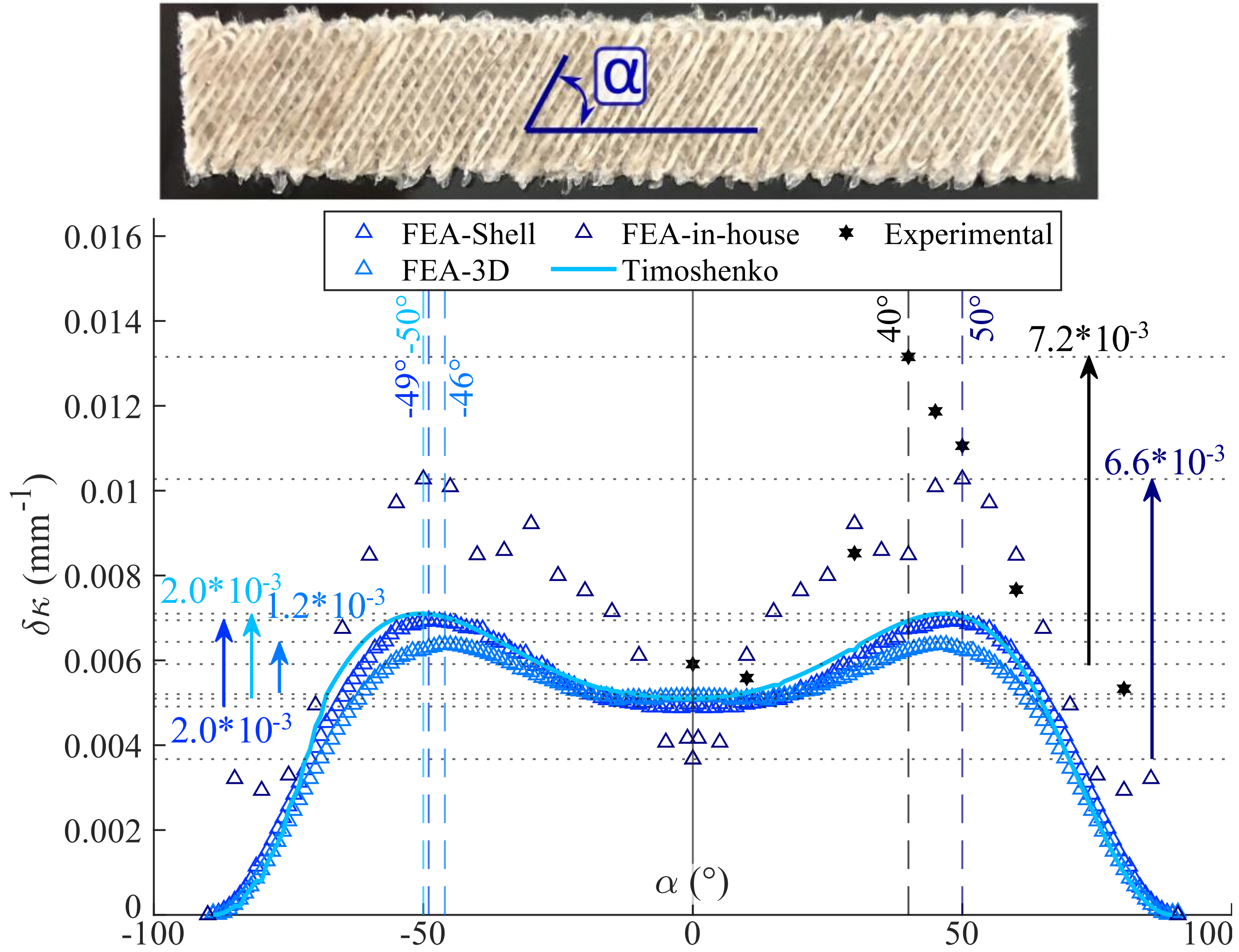
Angle-HBC



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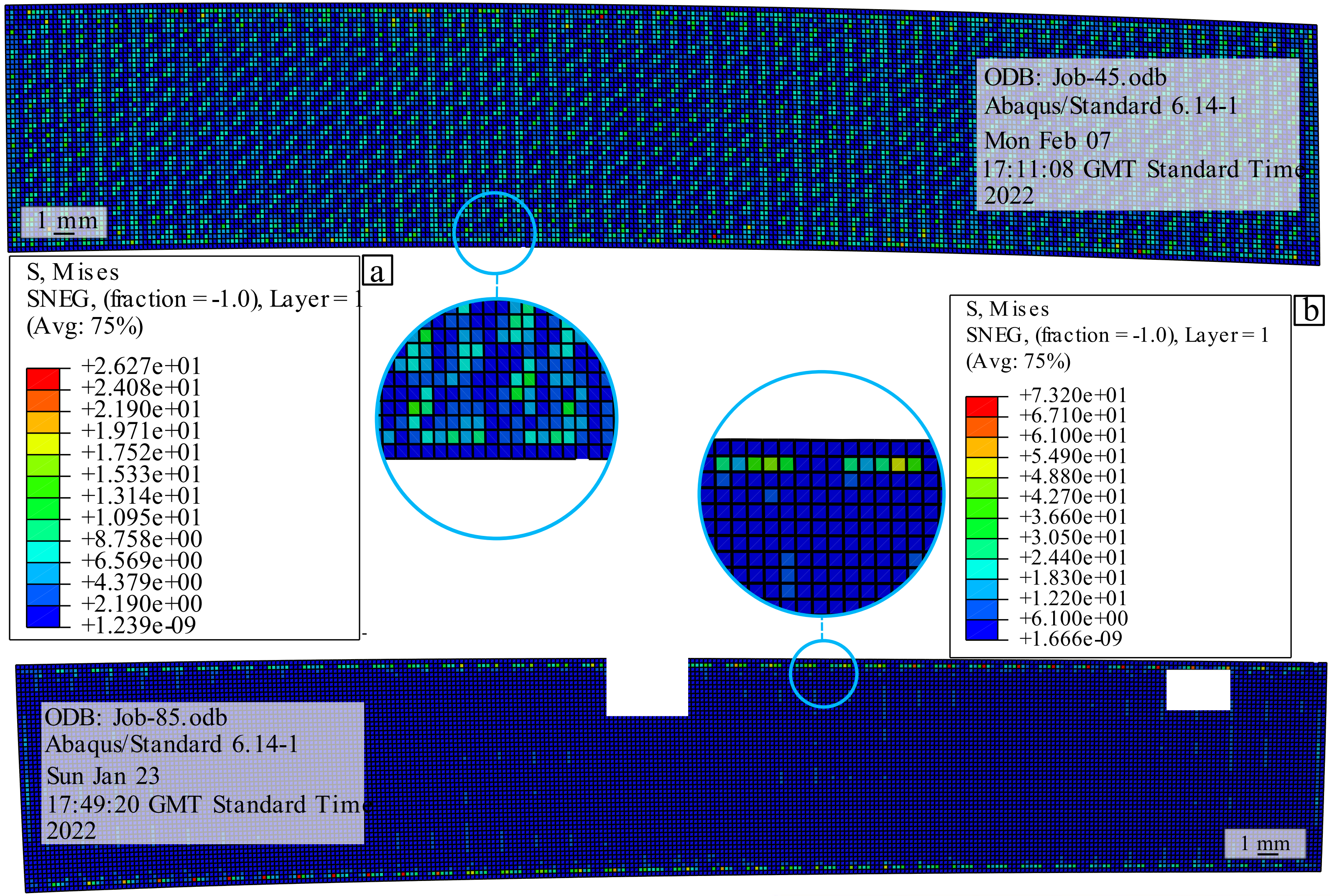
Angle-HBC



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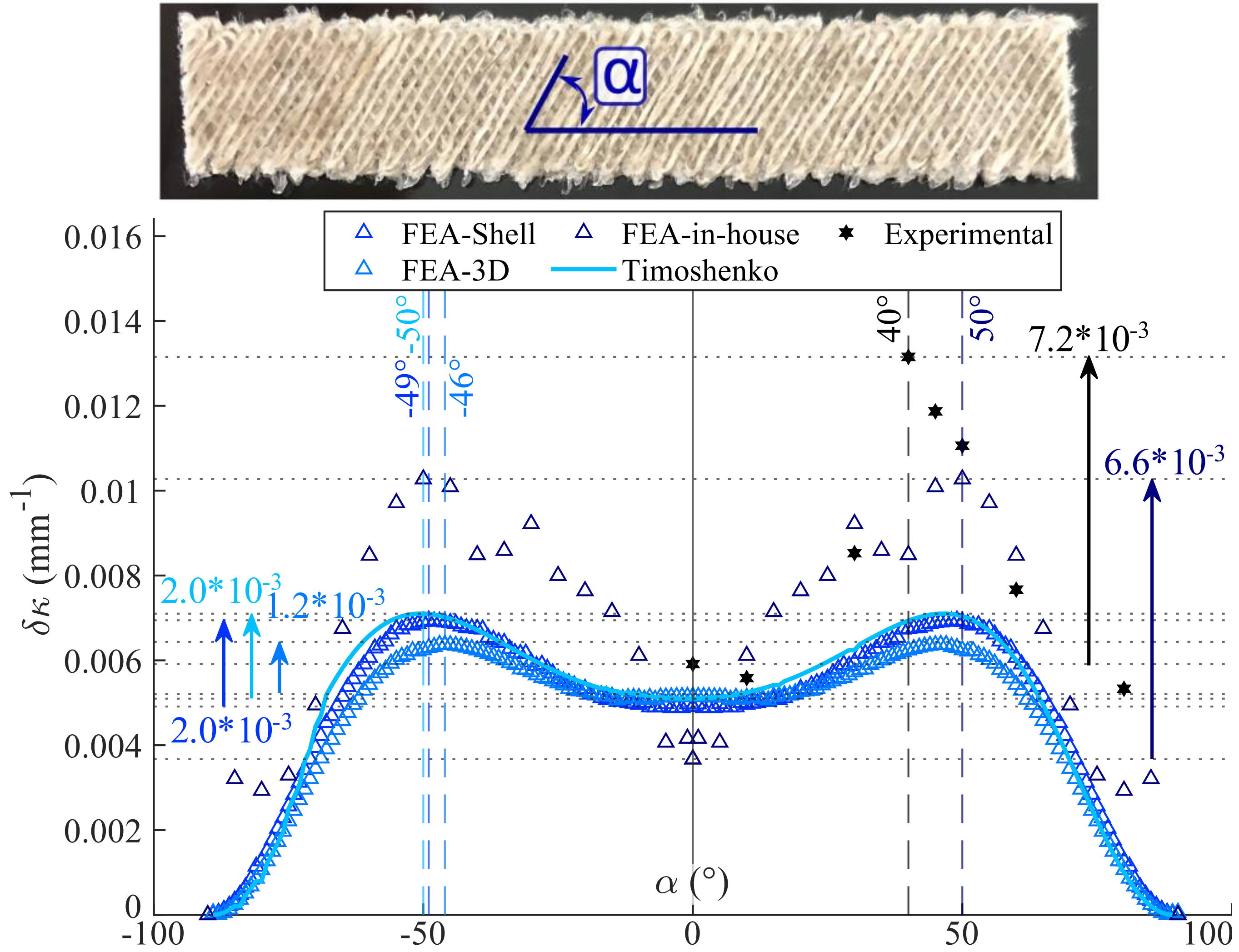
Angle-HBC



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What you can find in the paper:

1- Discuss **bio-inspiration** from calla lily flower

2- **Video gage test set up** for out-of-water actuation test

3- Test different printing patterns to **control actuation amplitude**

4- **Compare prediction models** for actuation (Analytical, Numerical)

5- Measure **speed of actuation** and discuss the influence of the stacking sequence

C. de Kergariou, et al. Design space and manufacturing of programmable 4D printed continuous flax fibre polylactic acid composite hygromorphs. Materials & Design, volume 225, p.111472 2023.

Conclusion

1- Improve the actuation amplitude by replacing [90°,0°,0°] stacking sequence with [90°,α°,α°] \ α ∈[40°,55°].

2- Speed at t=0 increases with amplitude. Permanent state reached at the same time.

3- Curving the filament of a cross ply specimen can be used to control the actuation amplitude but not the double curvature

4- We were able print a specimen bio mimicking calla lilly flower but the actuation lacked amplitude

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Thank you for the attention

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