

CONCEPTION ET IMPRESSION 4D MULTI-MATERIAUX

Frédéric DEMOLY

Professeur des Universités

Membre Junior de l'Institut universitaire de France



RDM
RÉSEAU DES MÉCANICIENS



institut
universitaire
de France



utbm
université de technologie
Belfort-Montbéliard



Fabrication additive (~41 ans, premier brevet, J-C. André, Université de Lorraine, France)

Complexité est gratuite

+ 200 000 articles

Incrémental

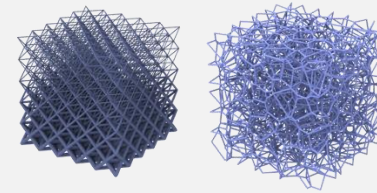
Forme



Fonctionnalité



Hiérarchique



Matériaux

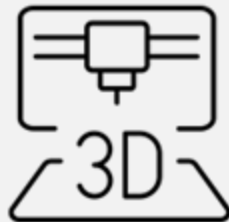


Impression 4D (~12 ans, S. Tibbits, MIT; M.L. Dunn, University of Colorado, H.J. Qi, GeorgiaTech)

Matériaux
actifs/passifs



Imprimante
3D



Stimuli

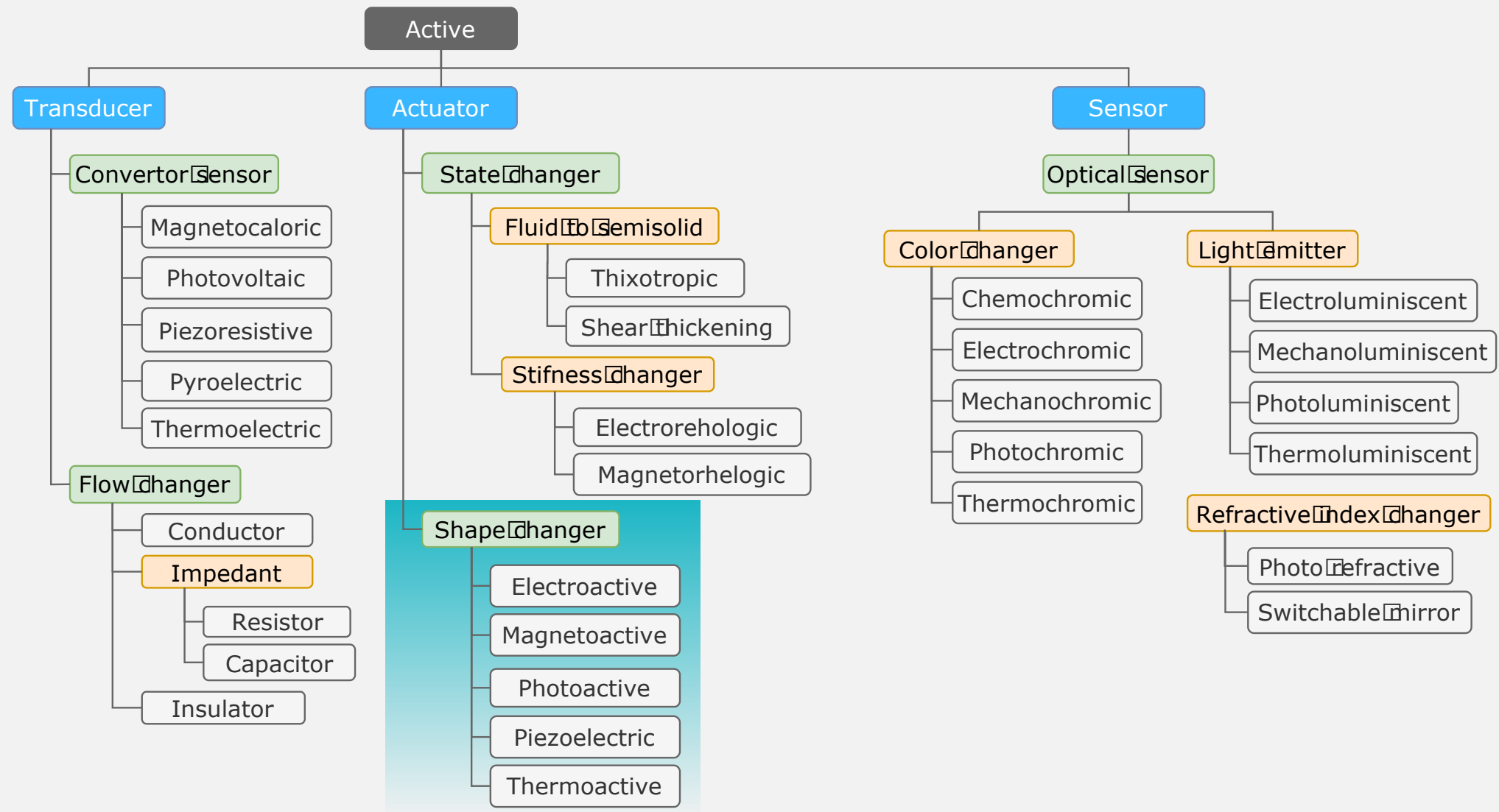


Complexité augmentée

+ 10 000 articles

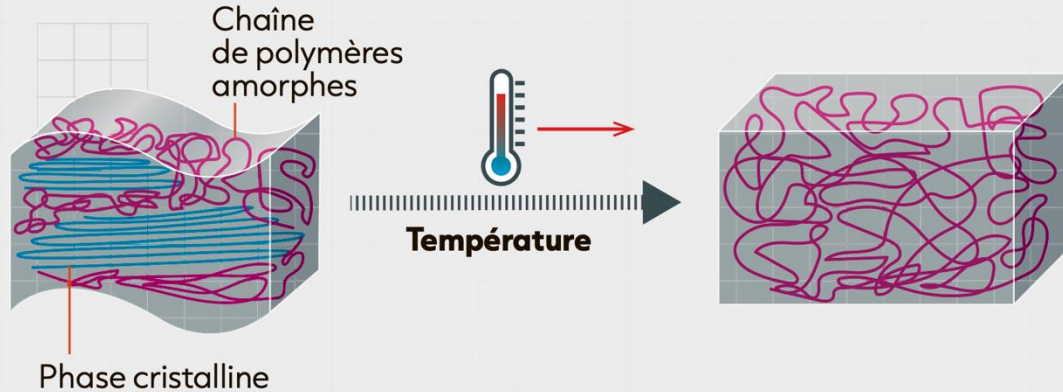
Interdisciplinaire

Disruptif



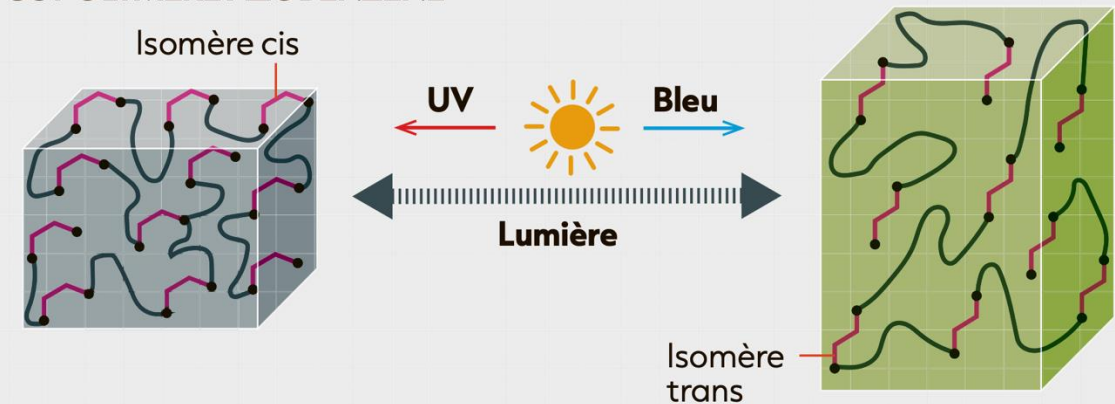
Réorganisation (ordre - désordre, séparation de phase...)

POLYMÈRE À MÉMOIRE DE FORME

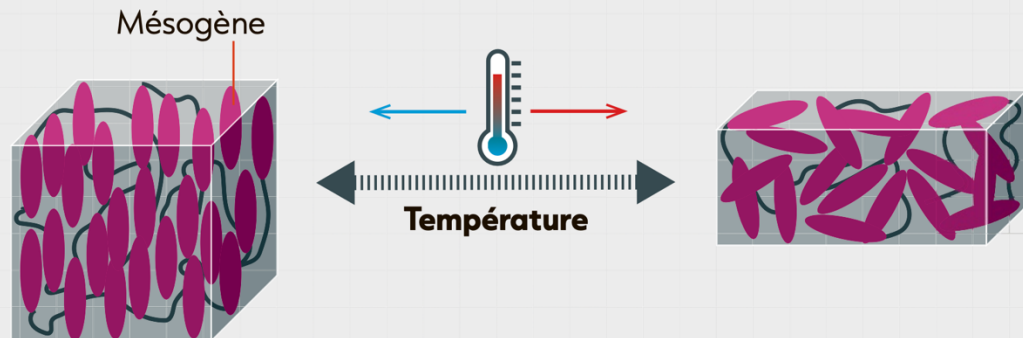


Réarrangement moléculaire (isomérisation, dimérisation...)

COPOLYMÈRE AZOBENZÈNE

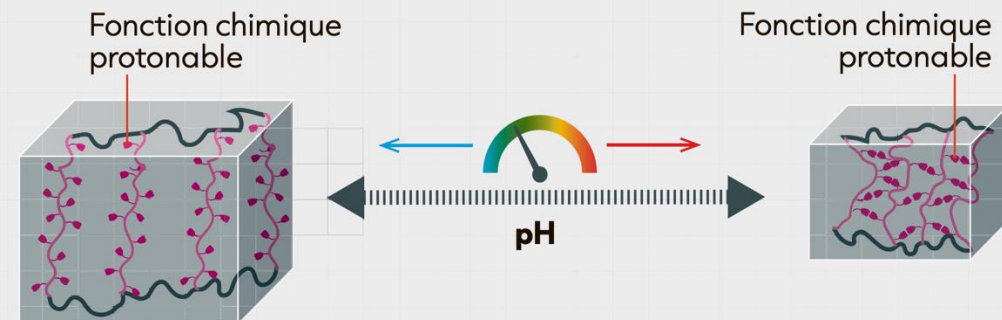


ÉLASTOMÈRE À CRISTAUX LIQUIDES

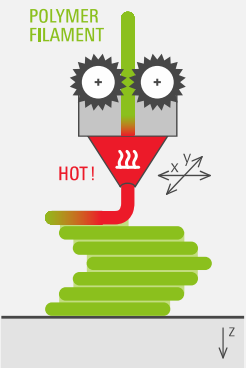


Changement d'interactions macromoléculaires

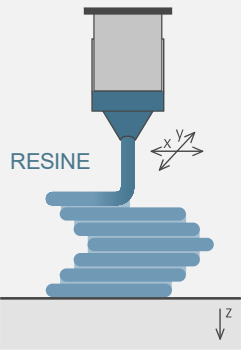
HYDROGEL



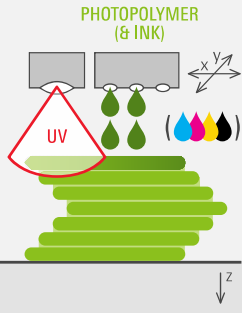
Fused Filament
Fabrication
(FFF)



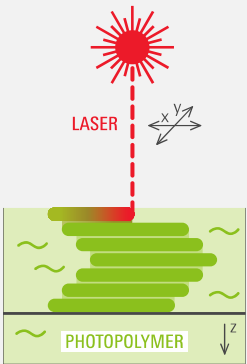
Direct Ink
Writing
(DIW)



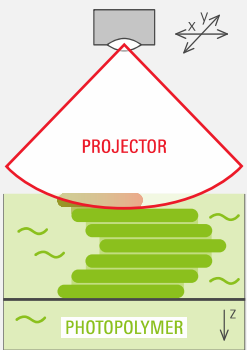
Material
Jetting
(MJ)



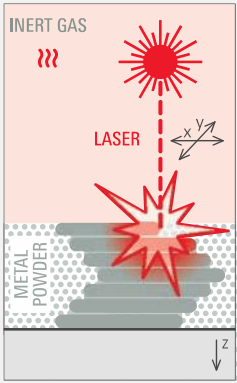
Stereolithography
(SLA)



Digital Light
Processing
(DLP)

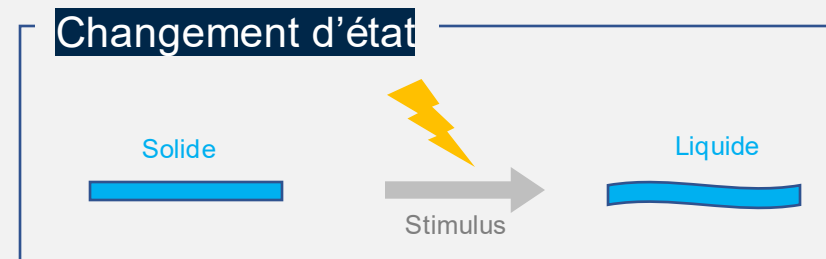
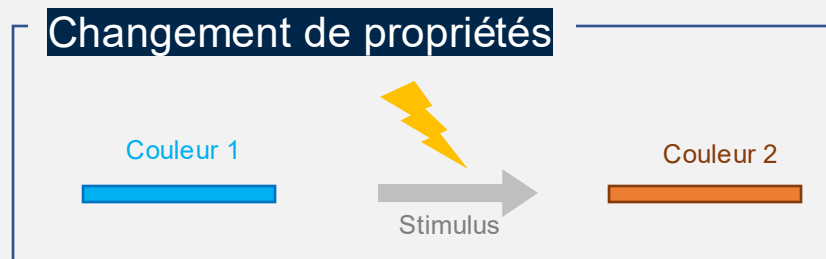
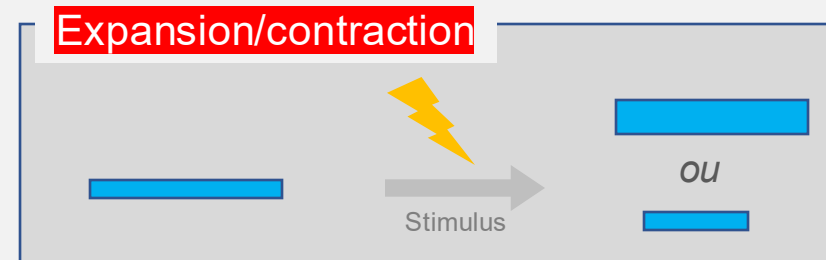
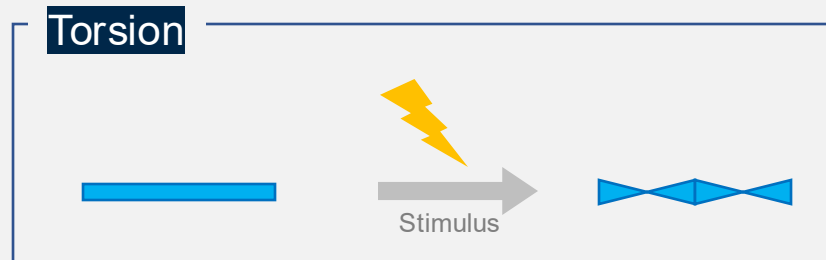
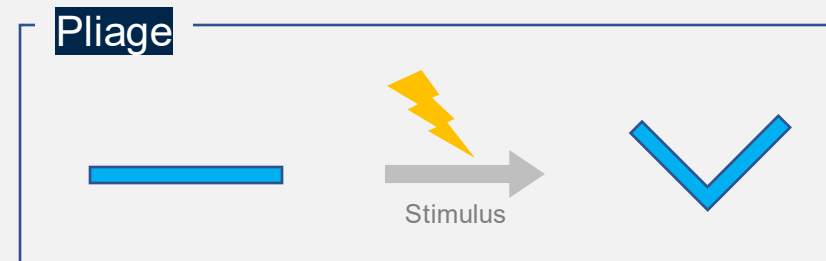
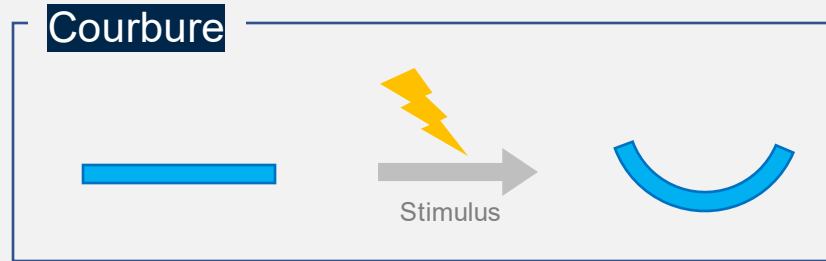


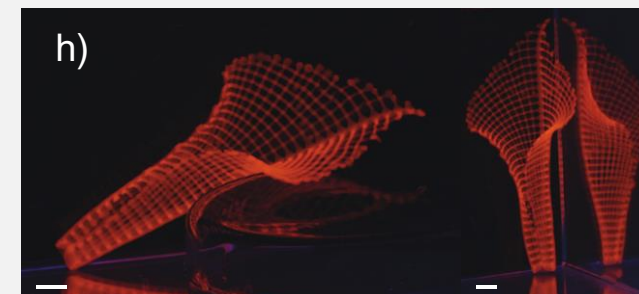
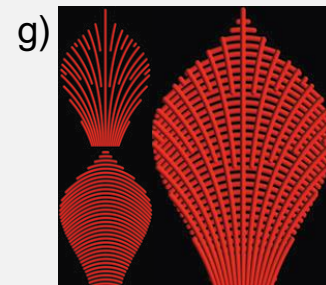
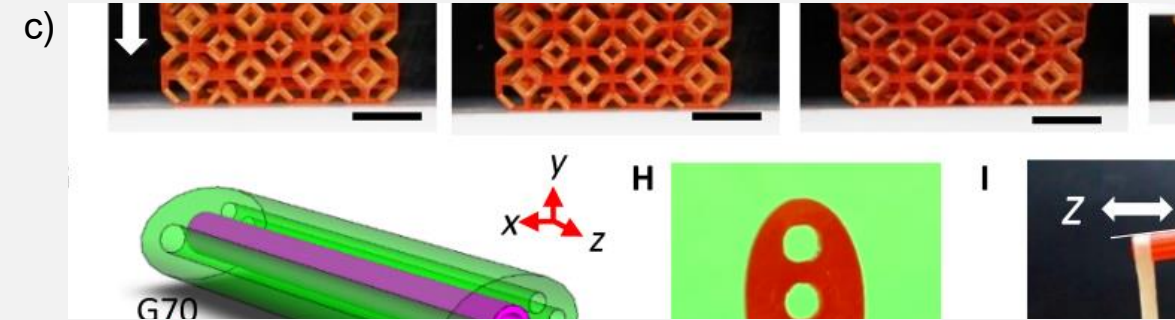
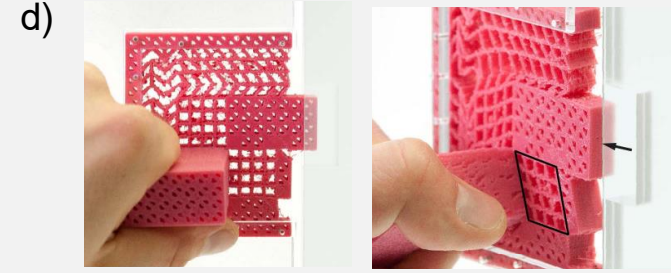
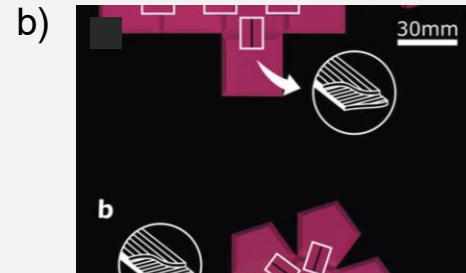
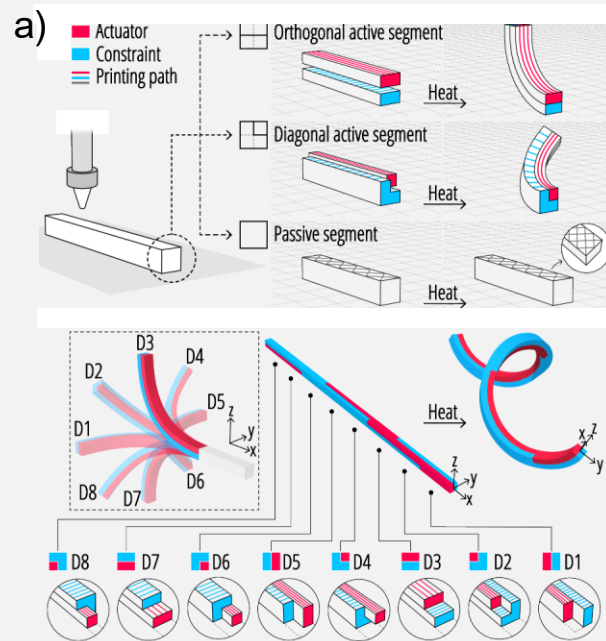
Selective Laser
Melting
(SLM)



← Impression multi-matériaux →

← Impression mono-matériau →

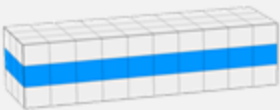




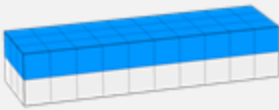
Techniques FA ajustées avec (a) matériaux passifs, (b) trajectoires d'impression and (c,d) structures cellulaires [Ion et al., 2016; van Manen et al., 2017; Kuang et al., 2019; Wang et al., 2019]

(e) bio-inspiration, (f) DIW de composite hydrogel, (c) trajectoire spécifique et (d) actionnement à partir d'humidité [Gladman et al., 2016]

[Dimassi et al., 2021]



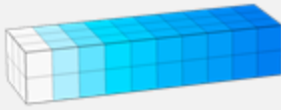
Sandwich



Bilame



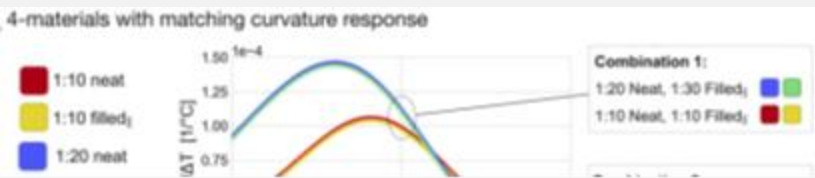
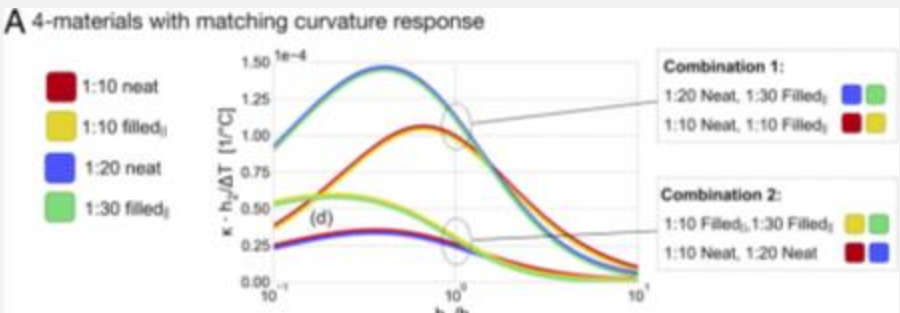
A motif



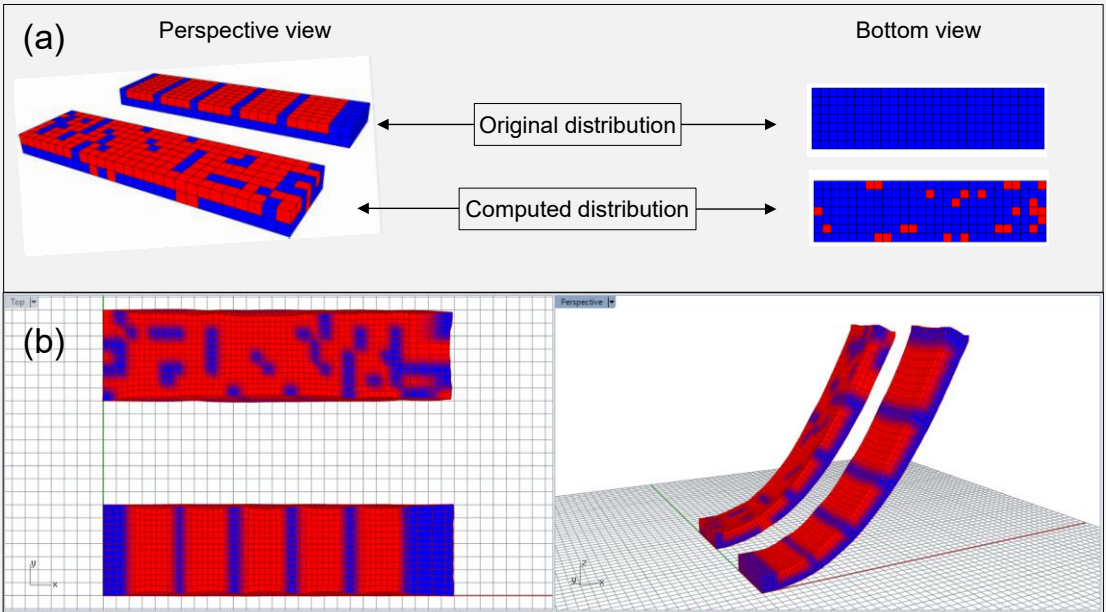
A gradient



Numérique



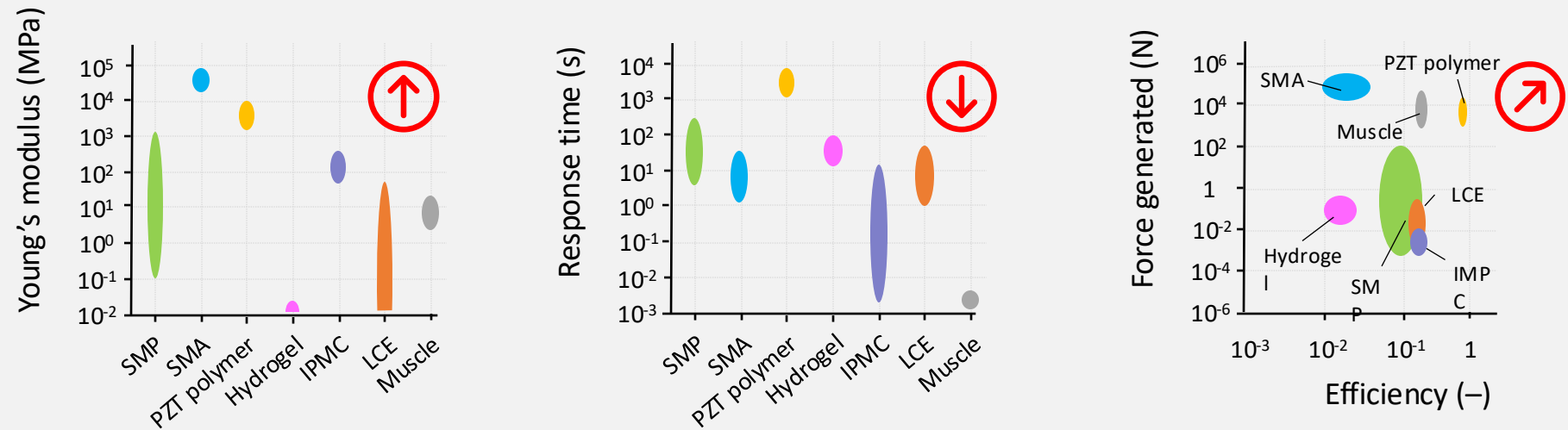
Structures multi-matériaux à sections contrôlées par DIW pour des courbures localisées [Boley et al., 2019]



Calcul à base de voxels constitués de matériaux passifs et actifs [Sossou et al., 2019a,b]

Performances mécaniques des actionneurs 4D

[Demoly et al., 2021]



Limitations des procédés

INTRA-DOMAINE

- Elaboration des matériaux actifs**
- Disponibilité
 - Besoin d'une étape d'ajustement
 - Dégradation sur plusieurs cycles
 - Comportement différents à travers les échelles

INTER-DOMAINE

- Procédés FA**
- Couplage matériau/procédé
 - Capacité multi-matériau
 - Anisotropie induite
 - Etape de post-traitement

INTRA-DOMAINE

- Stimulation**
- Effectivité temporelle
 - Externe et globale
 - Volume du stimulateur
 - Consommation énergétique

SPECIFIQUE et THEMATIQUE

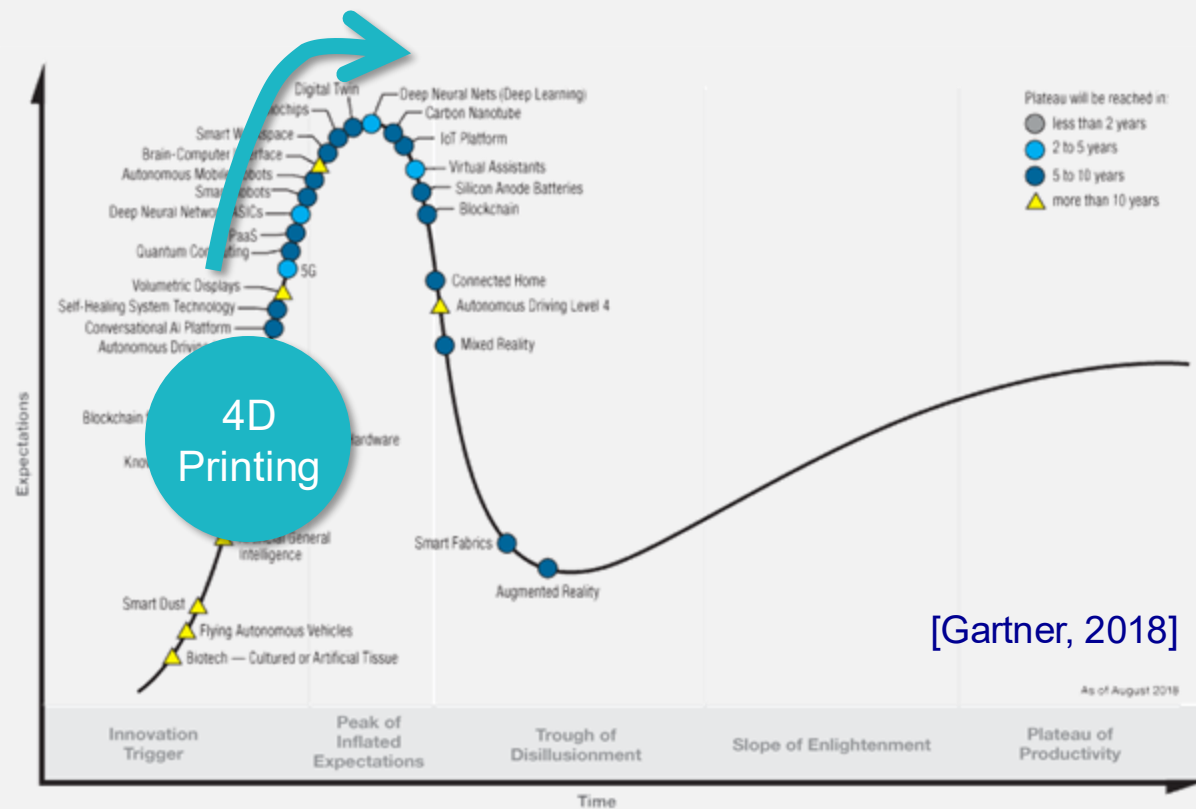
- Matériaux et procédés avancés
- Systèmes intelligents et intégrés
- Matière programmable
- *Material by design*

RÉGION
BOURGOGNE
FRANCHE
COMTE



STRATEGIQUE

- Augmenter la fonctionnalité des produits
- Systèmes intelligents pour la reconfiguration
- Produits physiques et jumeaux numériques
- Industrie 5.0, fabrication additive, robotique souple

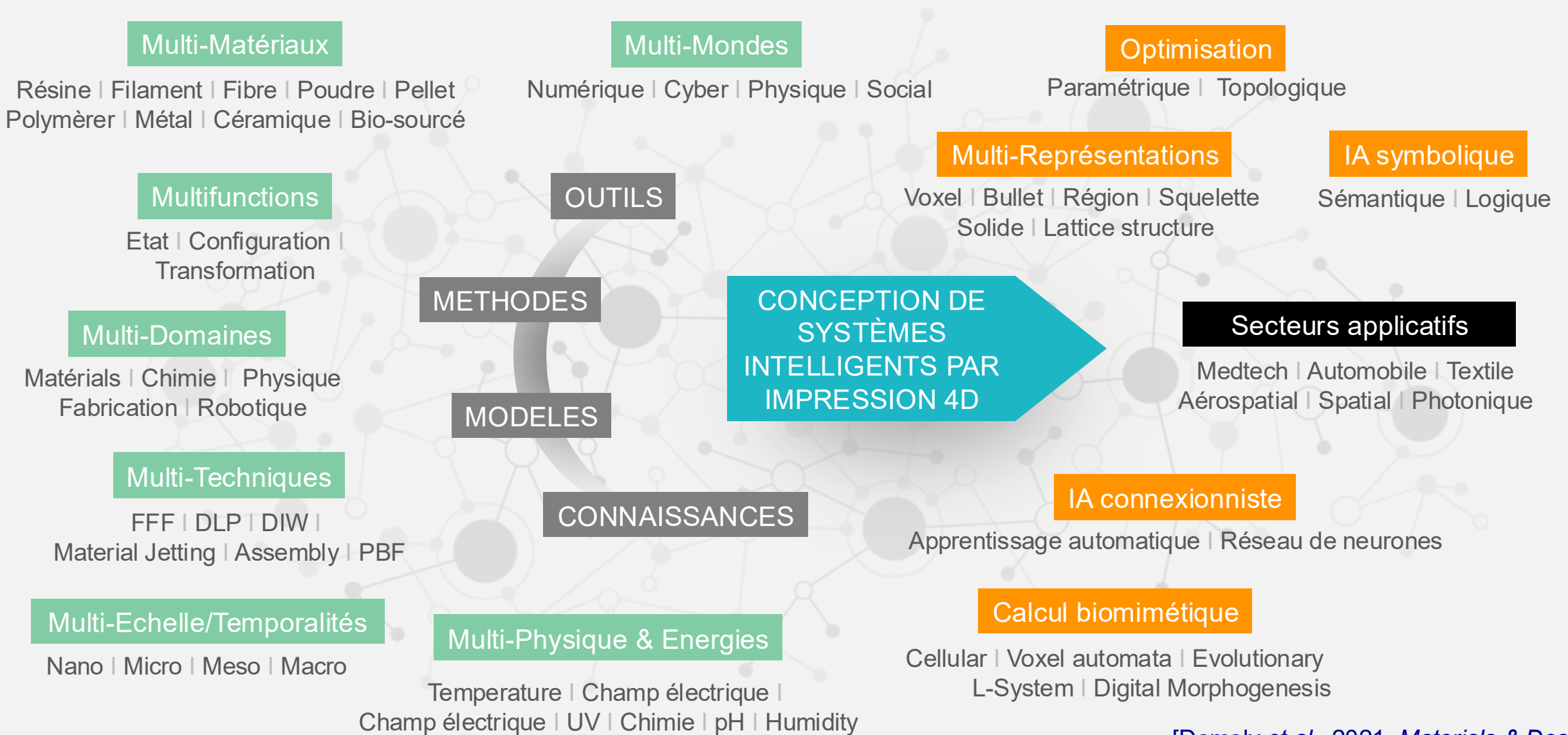


[Gartner, 2018]

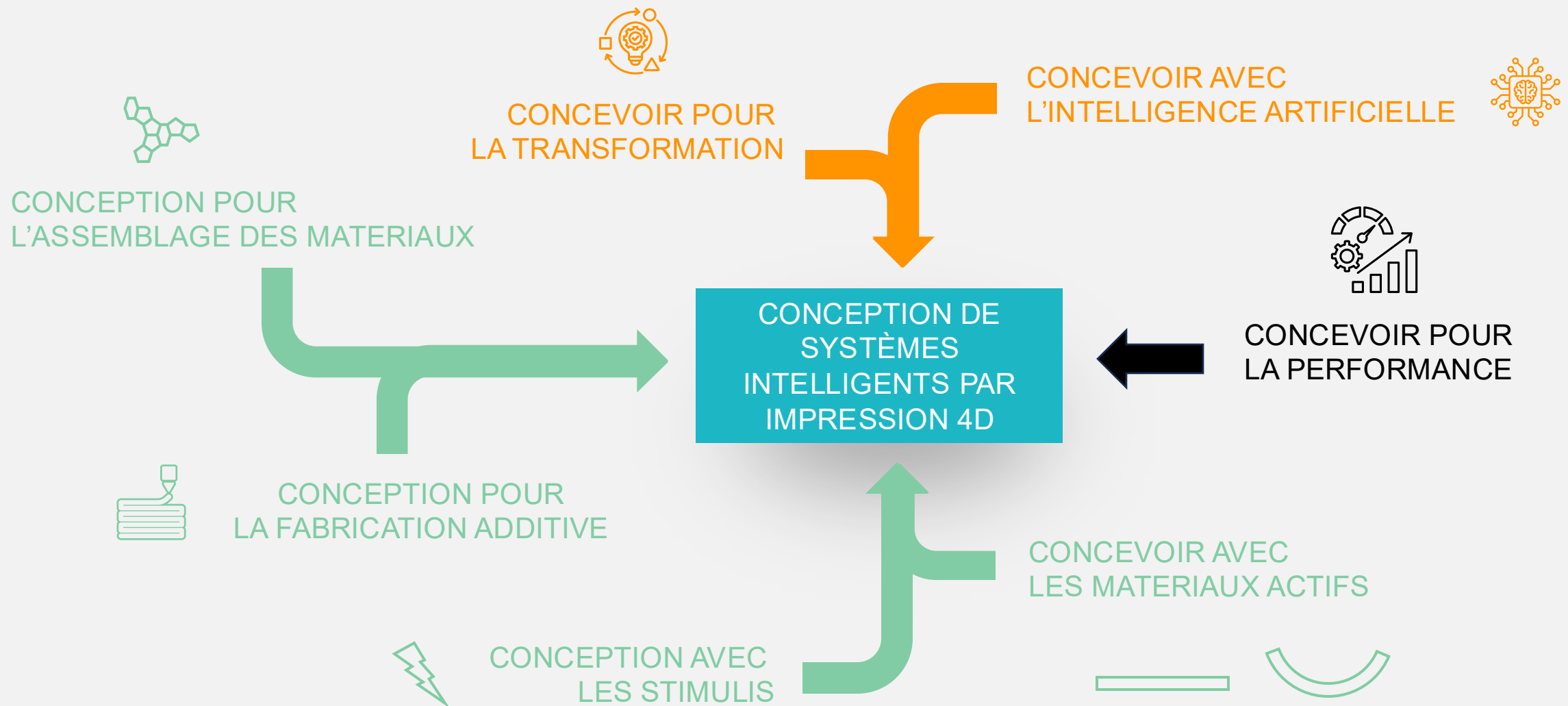
Méthodes de conception avancée
et chaîne numérique

Techniques de fabrication
avancée pour mécanismes à
changement de forme

Systèmes intelligents compatibles
avec l'Homme, les usages et
l'environnement

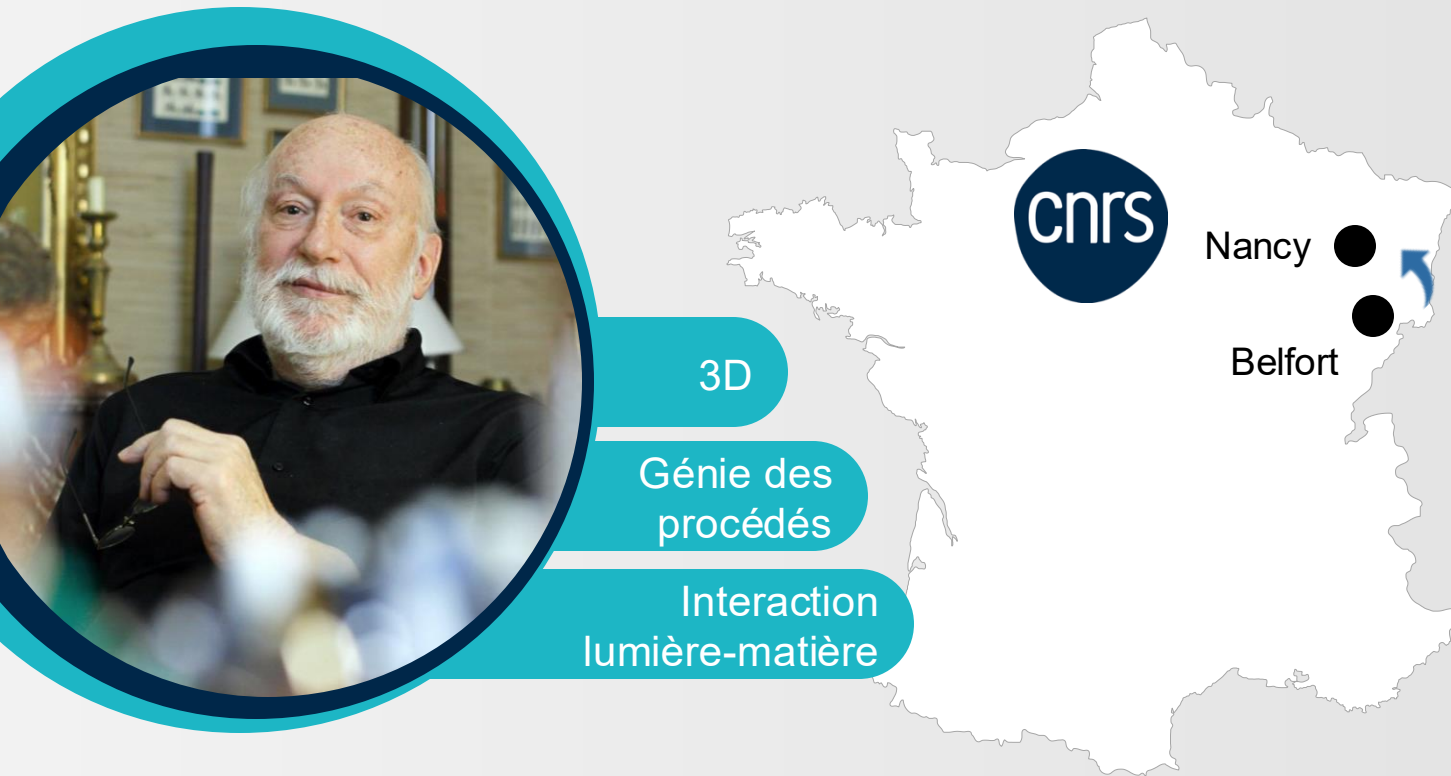


[Demoly *et al.*, 2021, *Materials & Design*]



IMPRESSION 4D

UNE HISTOIRE... AVANT TOUT HUMAINE



Jean-Claude ANDRÉ, Directeur de Recherche émérite CNRS
 Université de Lorraine
 Inventeur de l'impression 3D en 1984



IMPRESSION 4D

UNE HISTOIRE... AVANT TOUT HUMAINE



4D

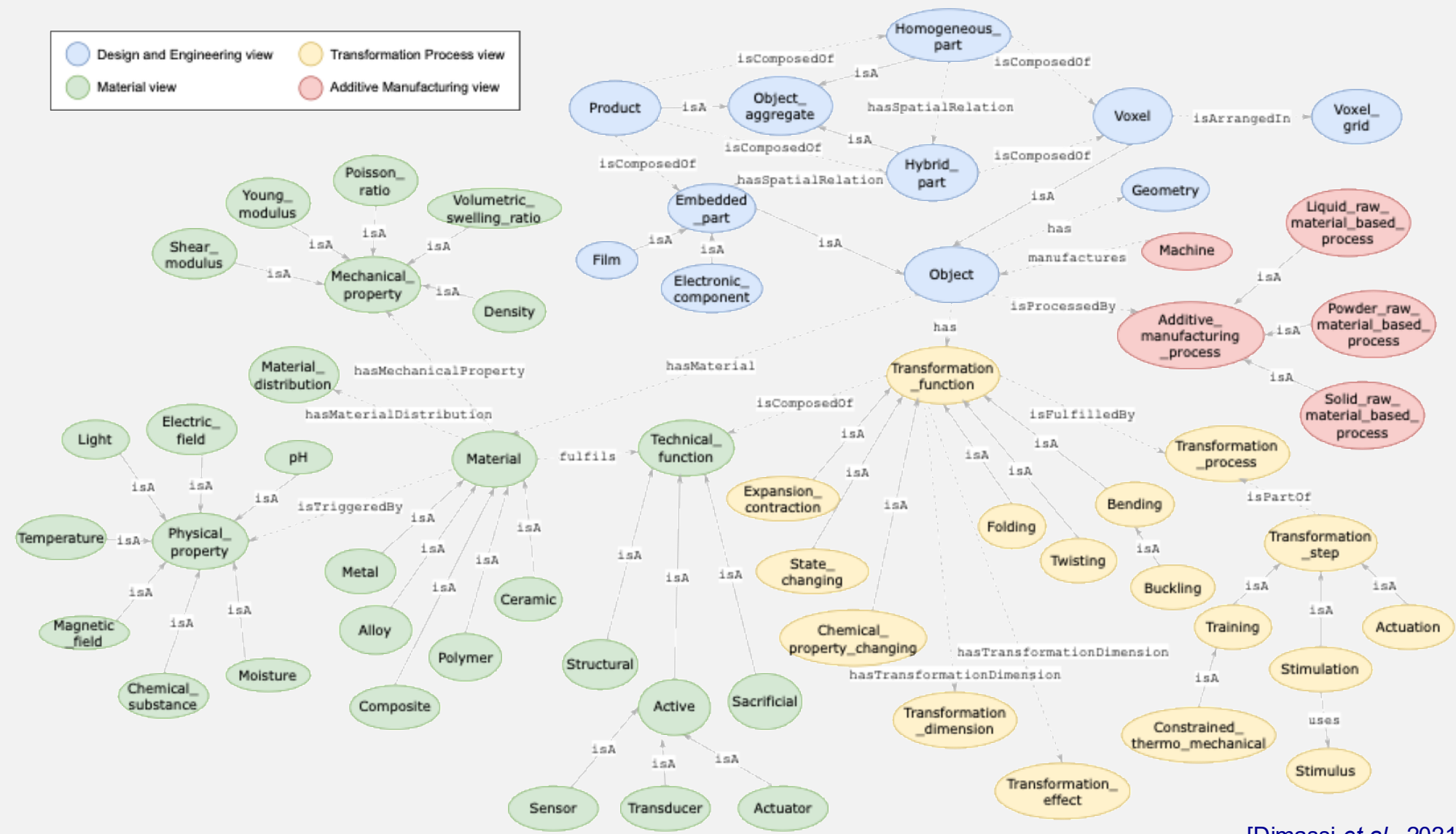
Mécanique
des matériaux

Matériaux
actifs souples

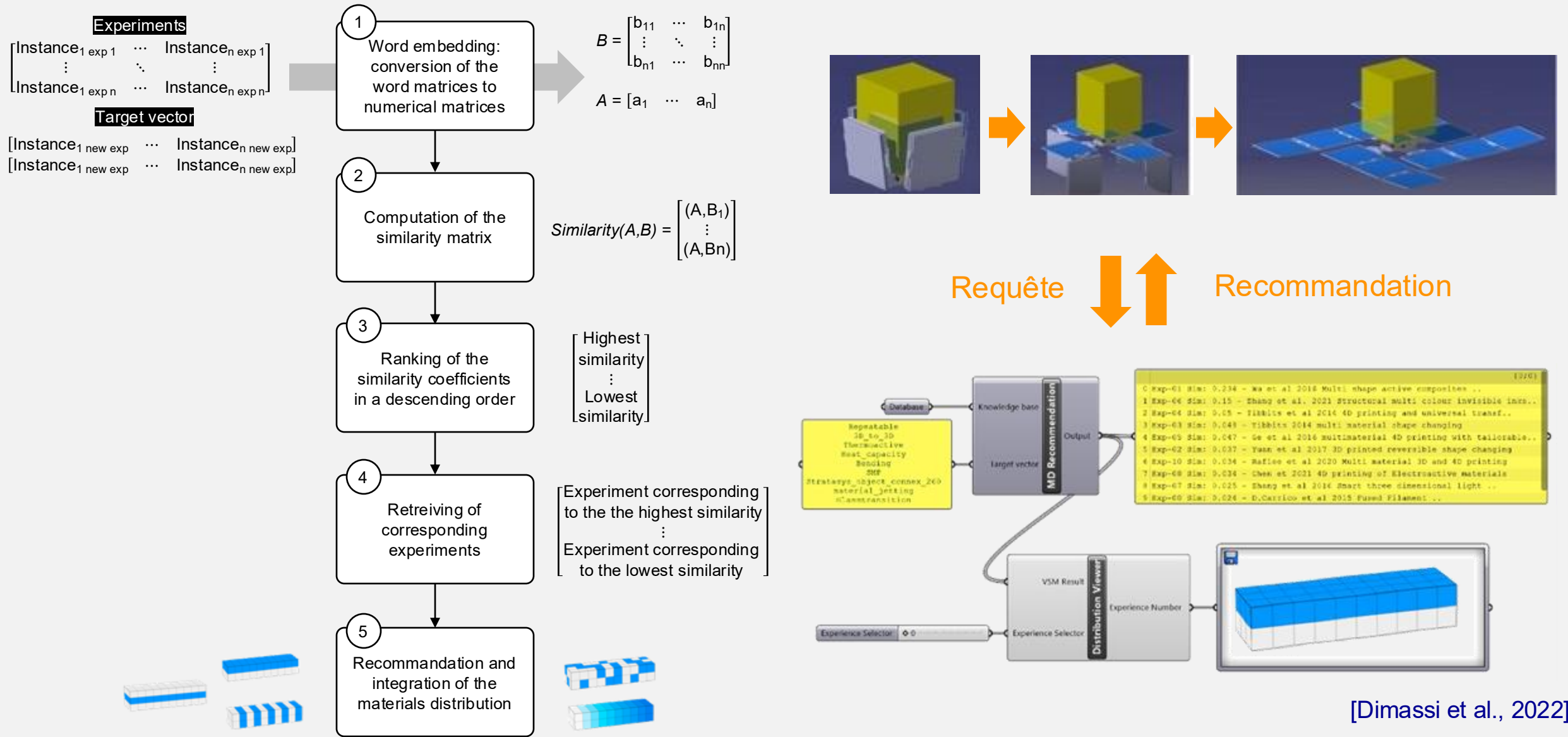
H. Jerry Qi

Georgia Institute of Technology
Inventeur de l'impression 4D en 2013





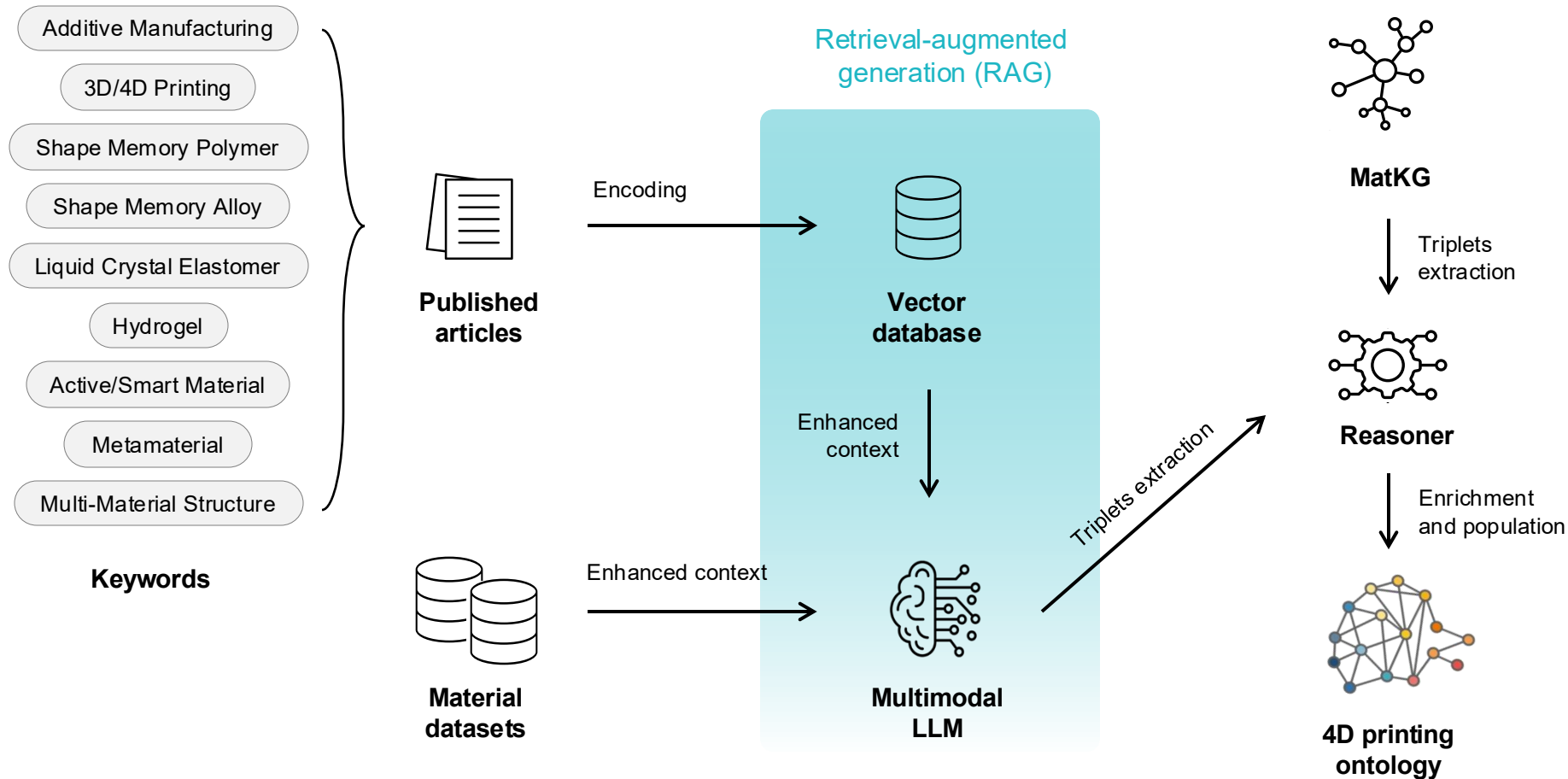
[Dimassi et al., 2021, Computers in Industry]



[Dimassi et al., 2022]



O. Bougzime



[Bougzime et al., 2025, Under review]



O. Bougzime

Retrieval-Augmented Multimodal Large Language Models For Ontology Enrichment in Rapidly Evolving 4D Printing

Oualid Bougzime¹, Christophe Cruz², Kun Zhou³,
H. Jerry Qi⁴, and Frédéric Demoly^{1,5}

¹ Université Marie et Louis Pasteur, UTBM, CNRS, ICB UMR 6303, France

² Université Bourgogne Europe, CNRS, ICB UMR 6303, France

³ Nanyang Technological University, Singapore

⁴ Georgia Institute of Technology, Atlanta, USA

⁵ Institut universitaire de France (IUF), France

1,500 published articles

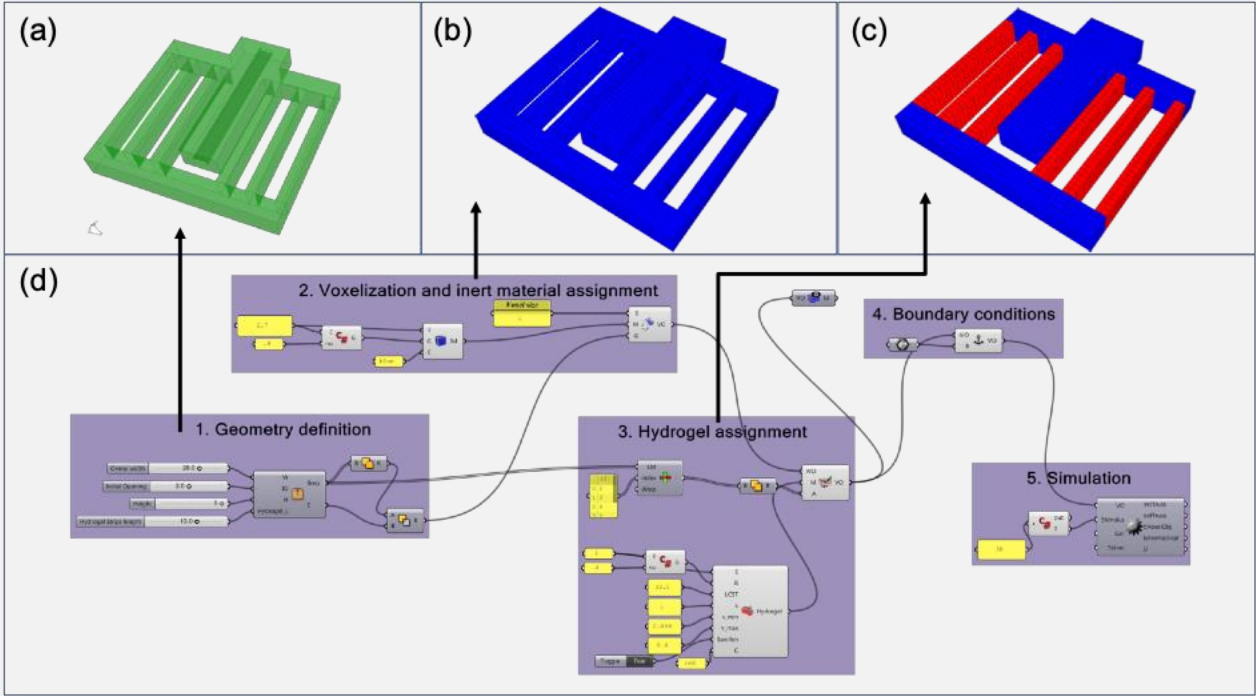
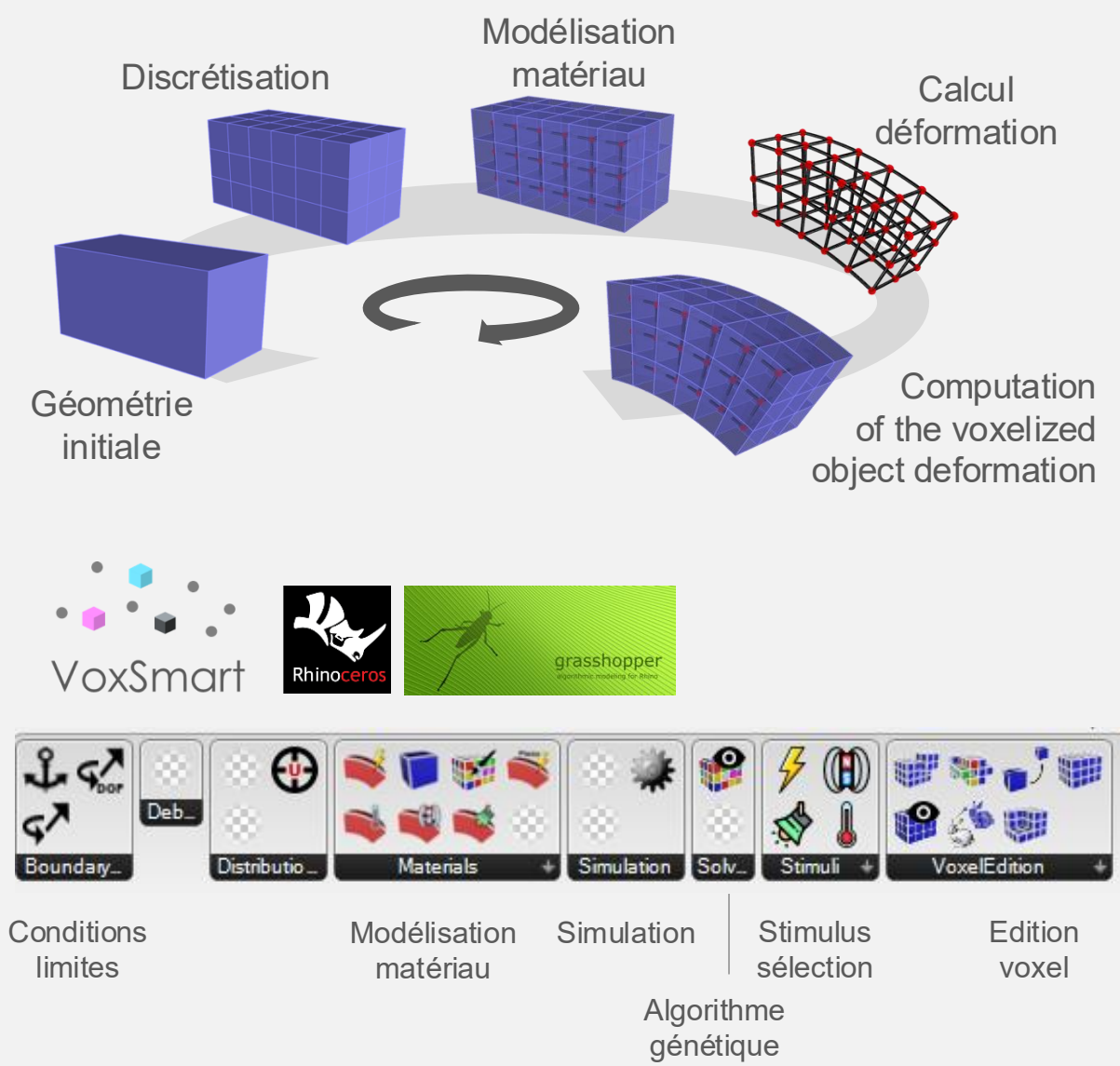
~5,800 classes
(knowledge concepts)

~12M instances
(data)

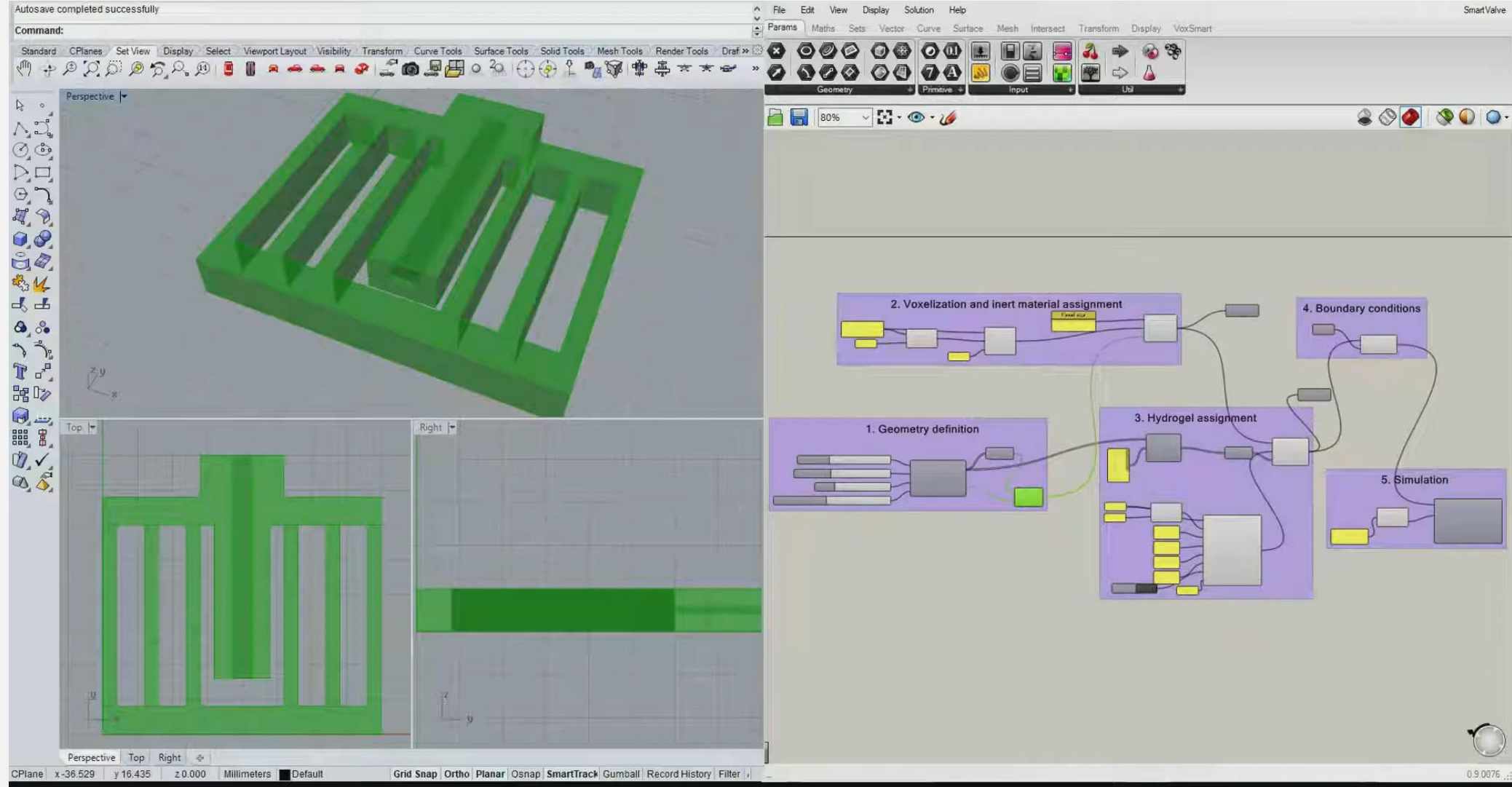
~1,300 object properties
(semantic links)

...

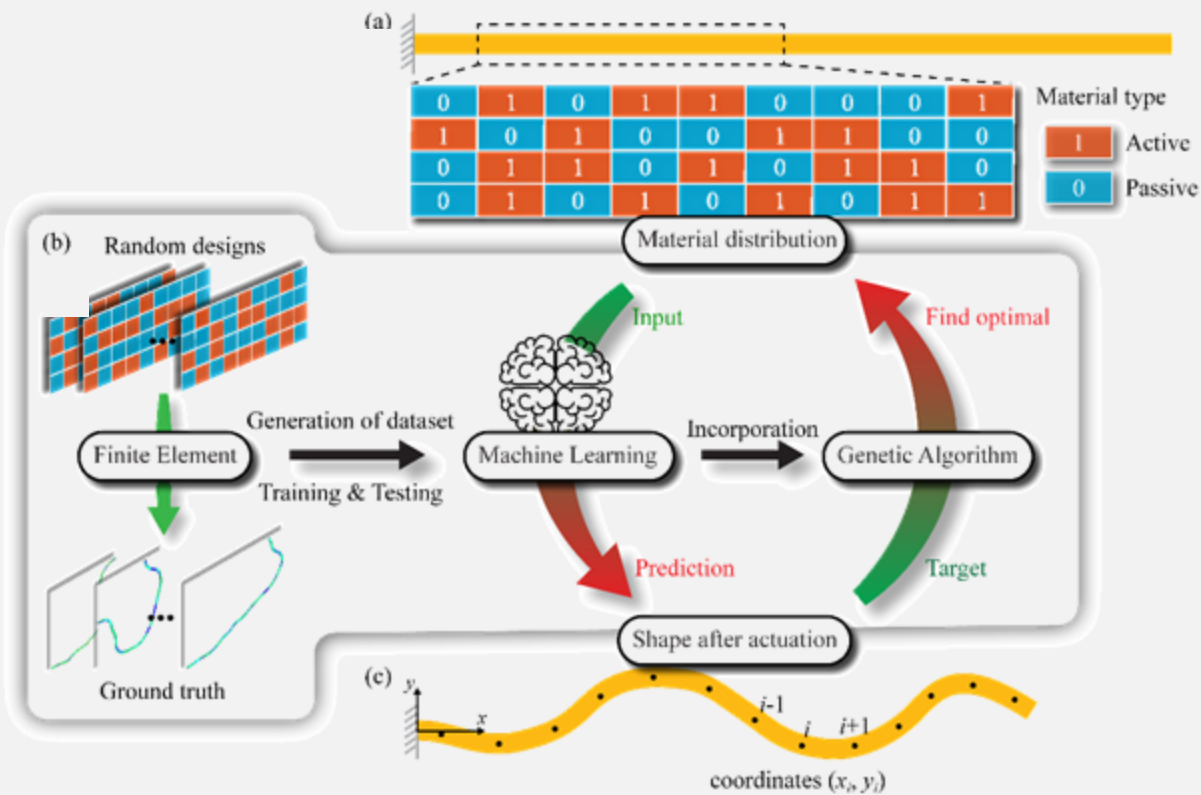
[Bougzime *et al.*, 2025, *Under review*]



[Sossou et al., 2019]



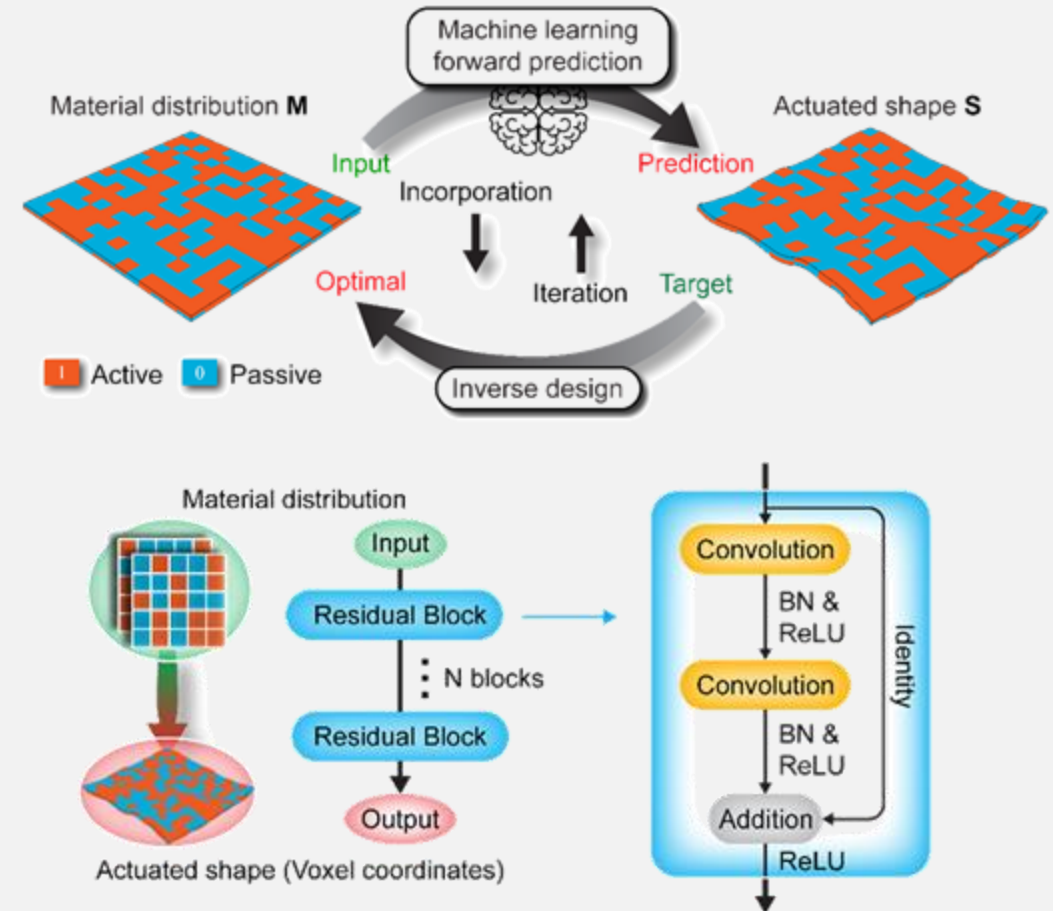
Structures actives 1D



[Hamel *et al.*, 2019, *Smart Materials and Structures*]

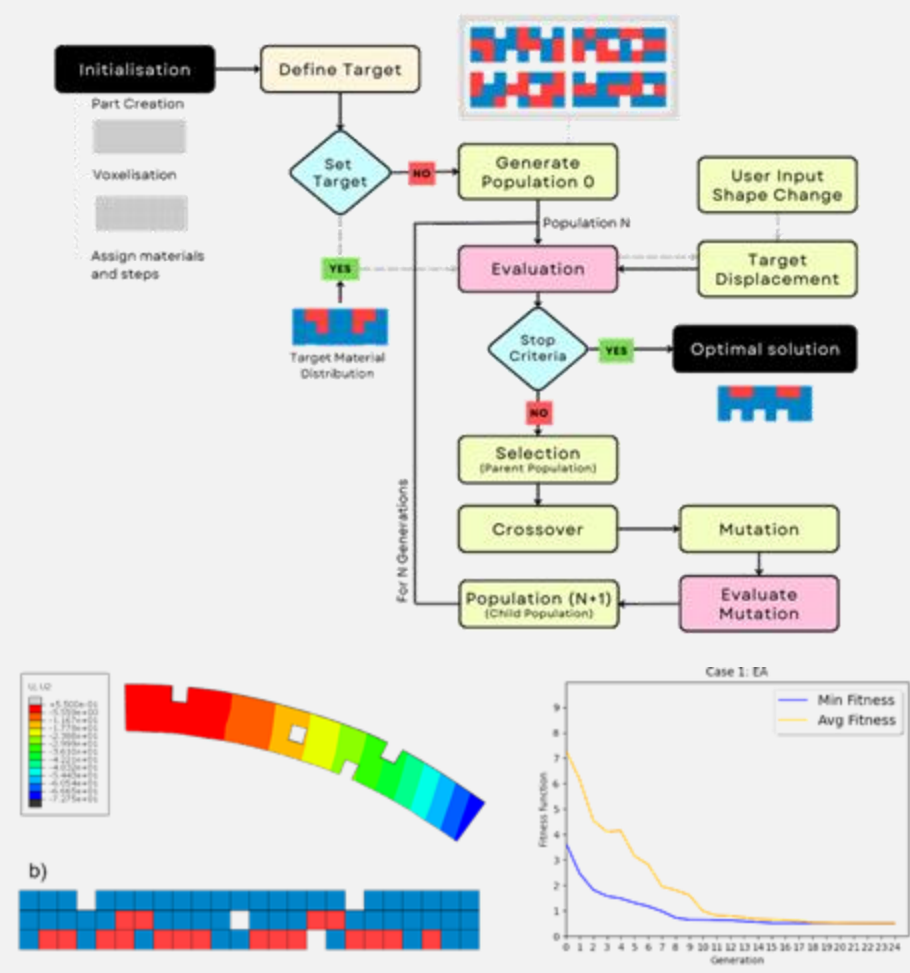
[Sun *et al.*, 2014, *Journal of the Mechanics and Physics of Solids*]

Structures actives 2D



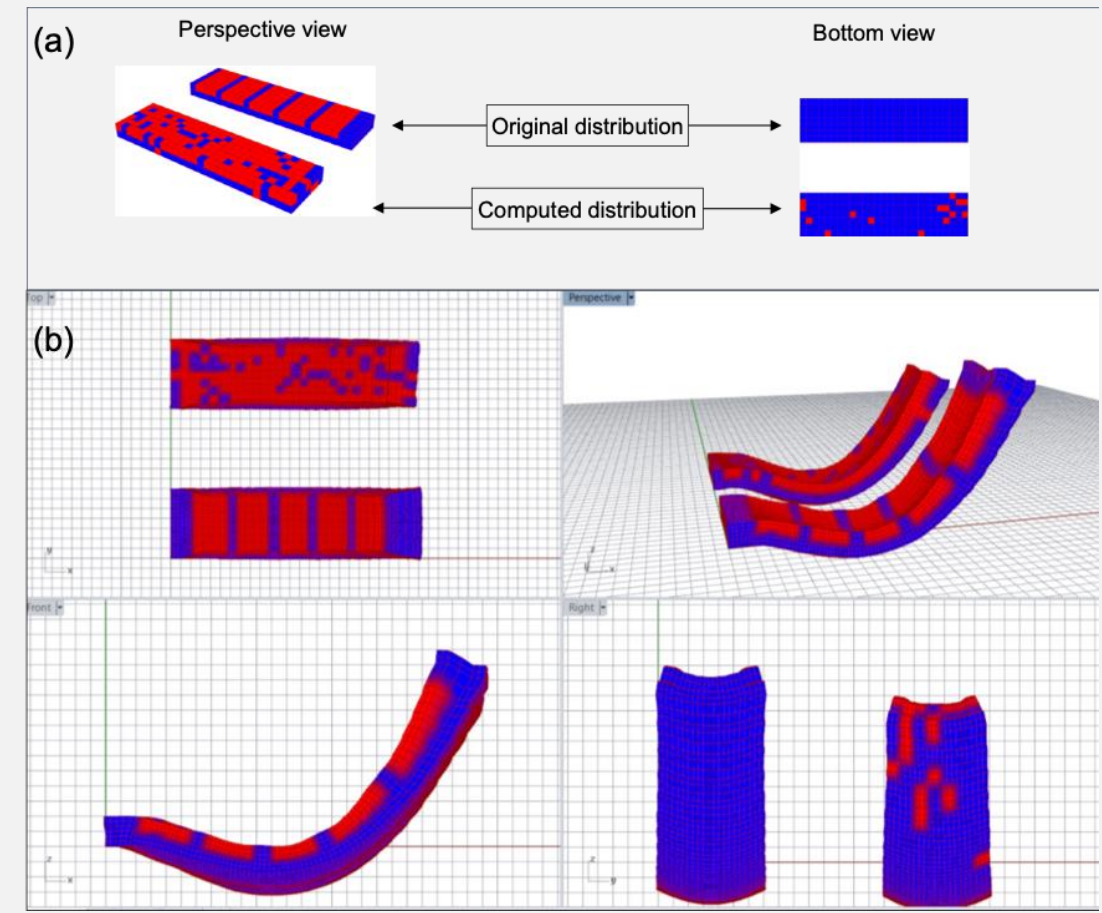
[Sun *et al.*, 2024, *Nature Communications*]

Structures actives 2D optimisées



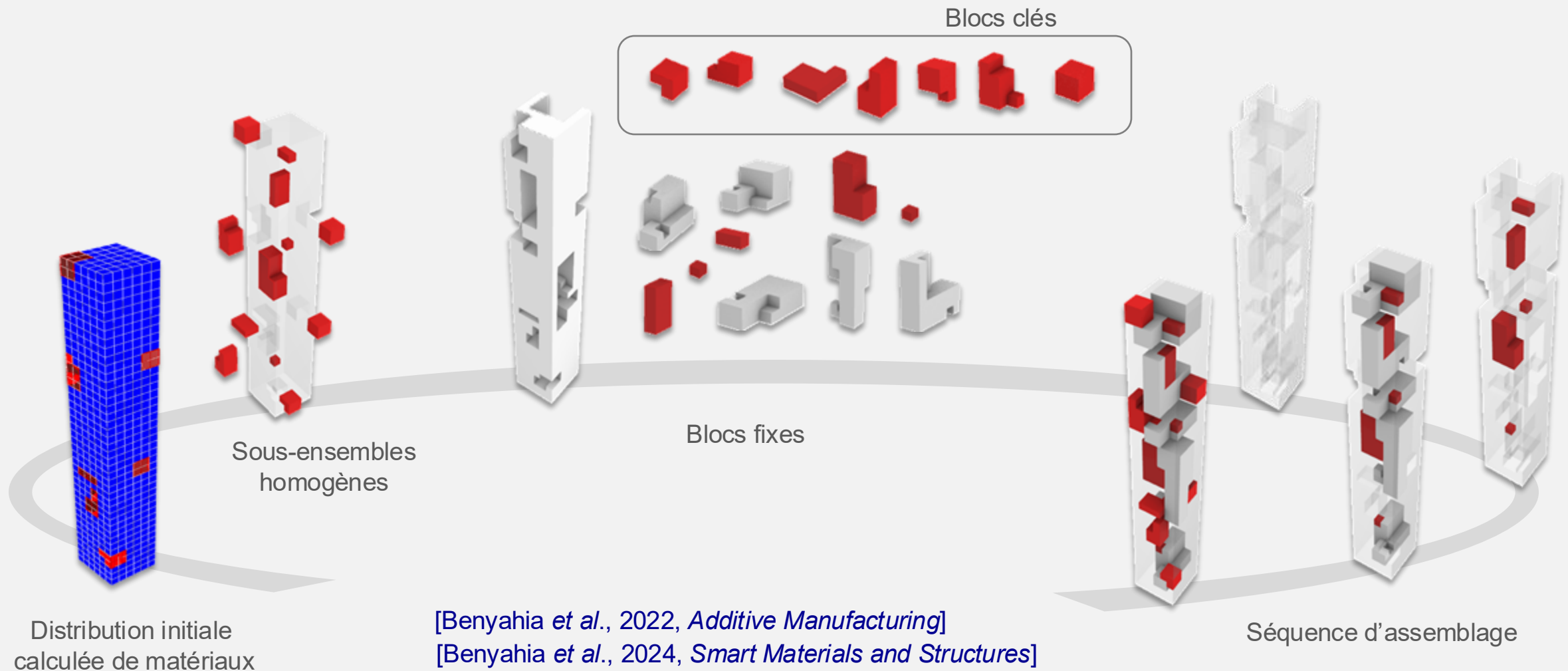
[Athinarayanarao *et al.*, 2023, *npj Computational Materials*]

Structures actives 3D

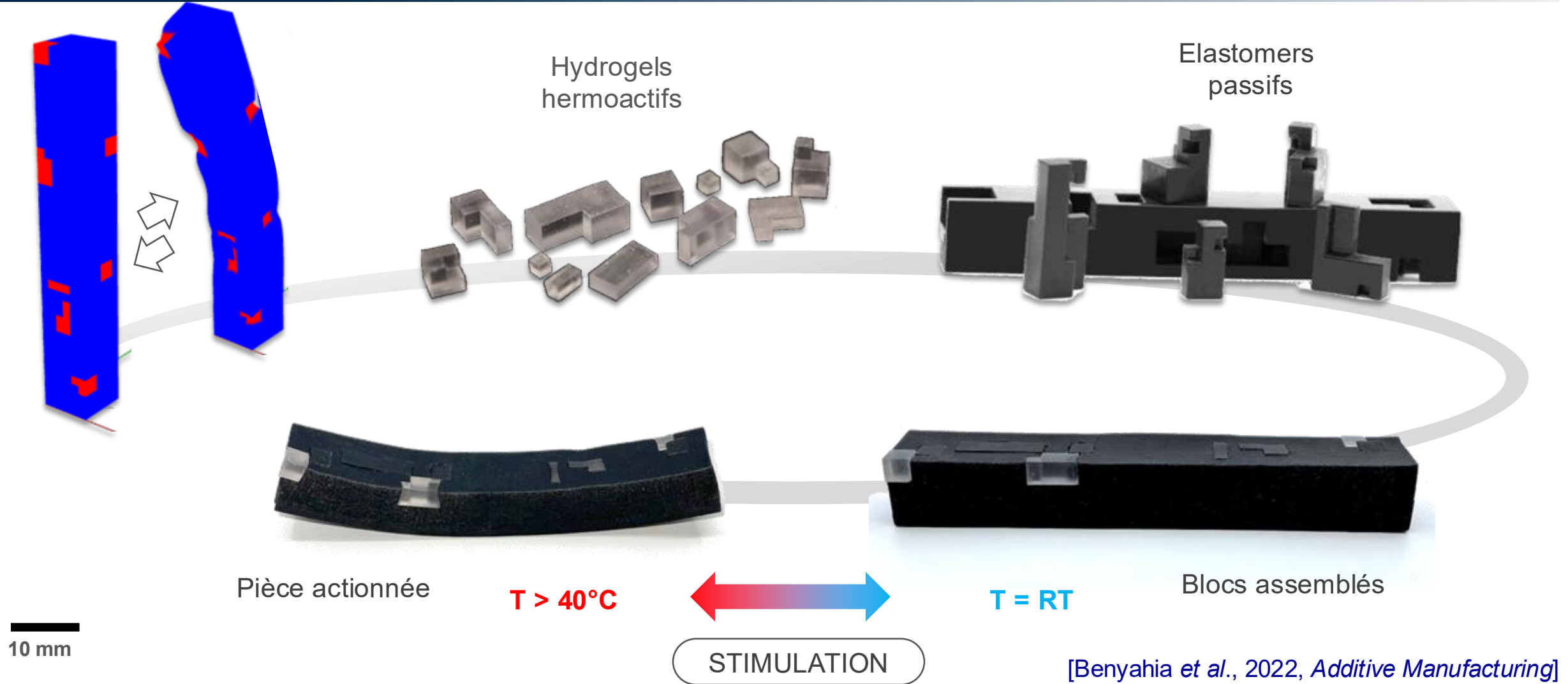


[Sossou *et al.*, 2019, *Materials & Design*]

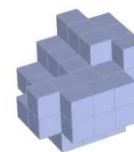
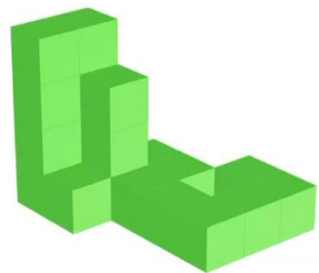
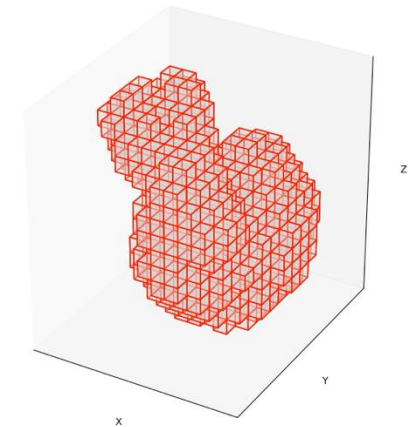
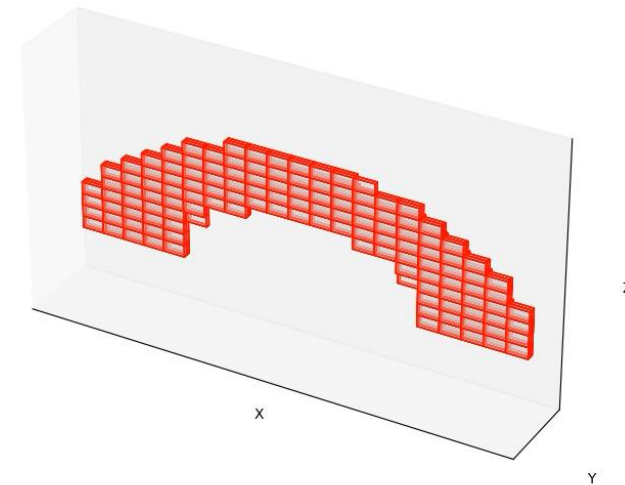
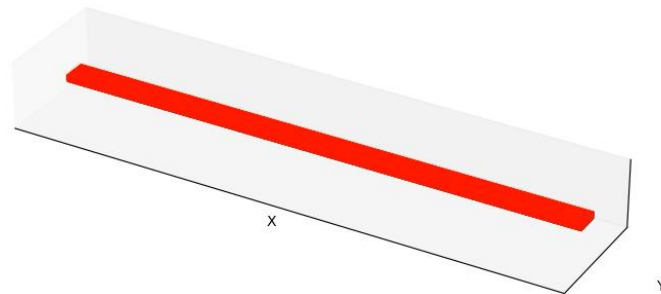
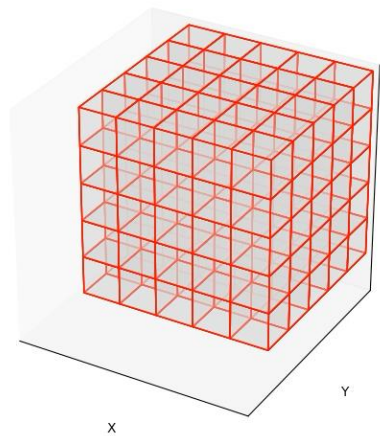
...à base de blocs emboîtés pour l'impression 4D multi-matériaux



...à base de blocs emboîtés pour l'impression 4D multi-matériaux

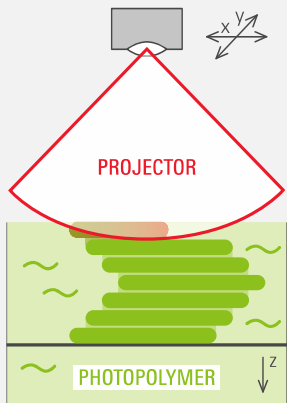


H. Seriket



[Seriket *et al.*, 2025, *Under review*]

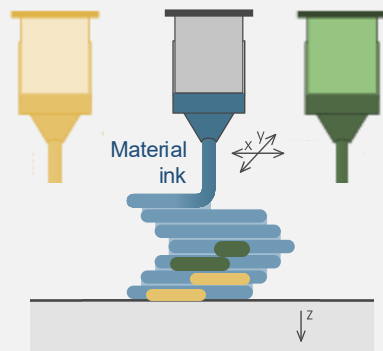
Pixel-Level Grayscale DLP



+

Pixel-level grayscale

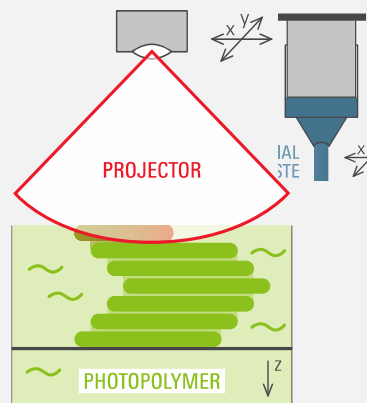
Multi-head DIW



+

Light irradiation

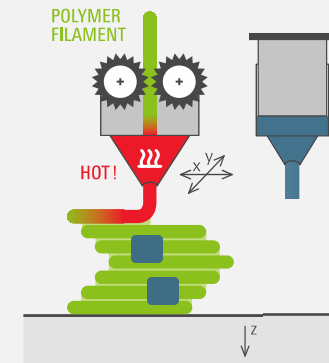
Hybrid DIW & DLP



+

UV irradiation

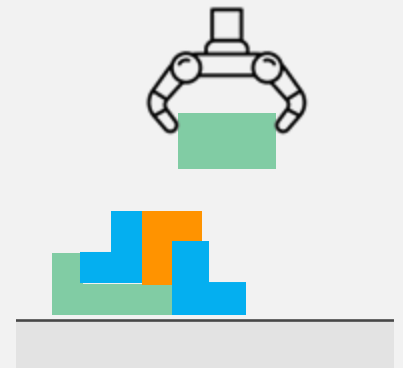
Hybrid DIW & FFF



+

UV irradiation

Robotic Assembly

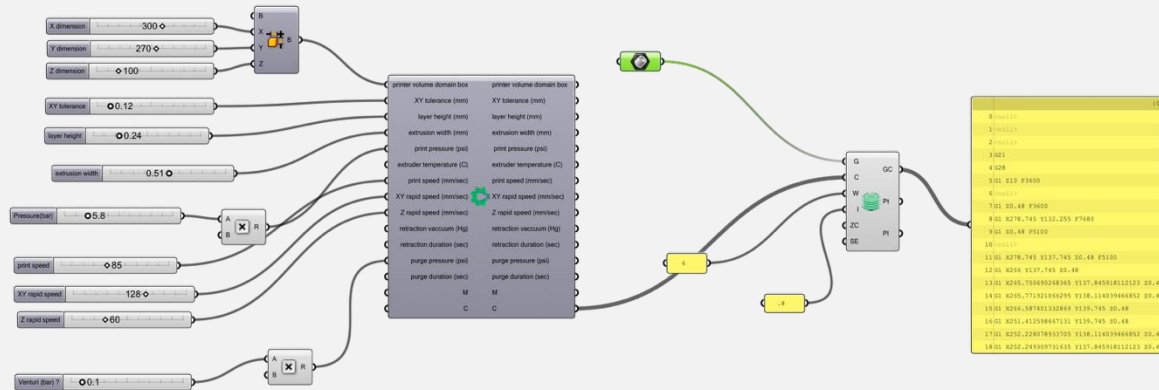


+

(UV irradiation)

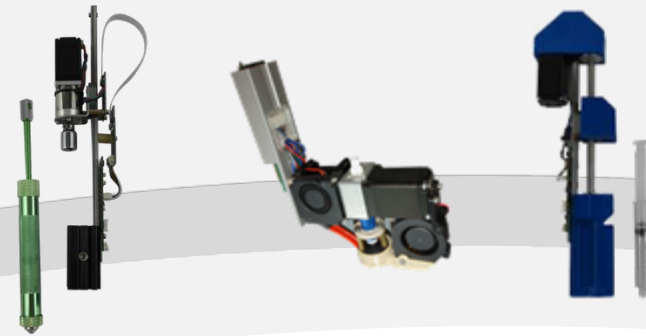
CAPACITÉ À COMBINER DES MATÉRIAUX DANS L'ESPACE DE CONCEPTION

Process planner/slicer (Rhino/Grasshopper) + machine customisée

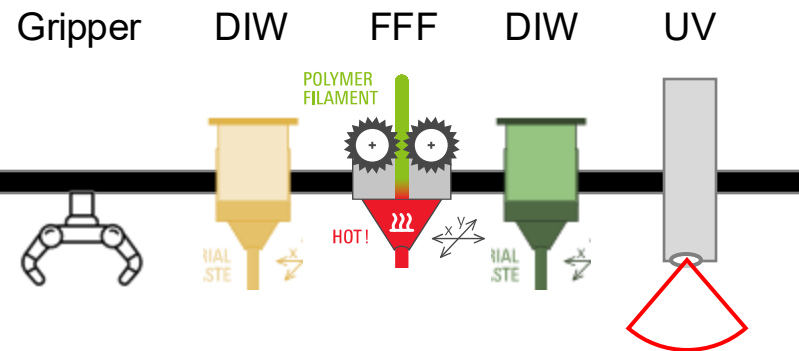
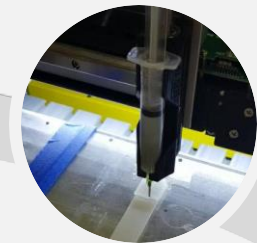


Upgraded multi-technique and multi-material 3D printer

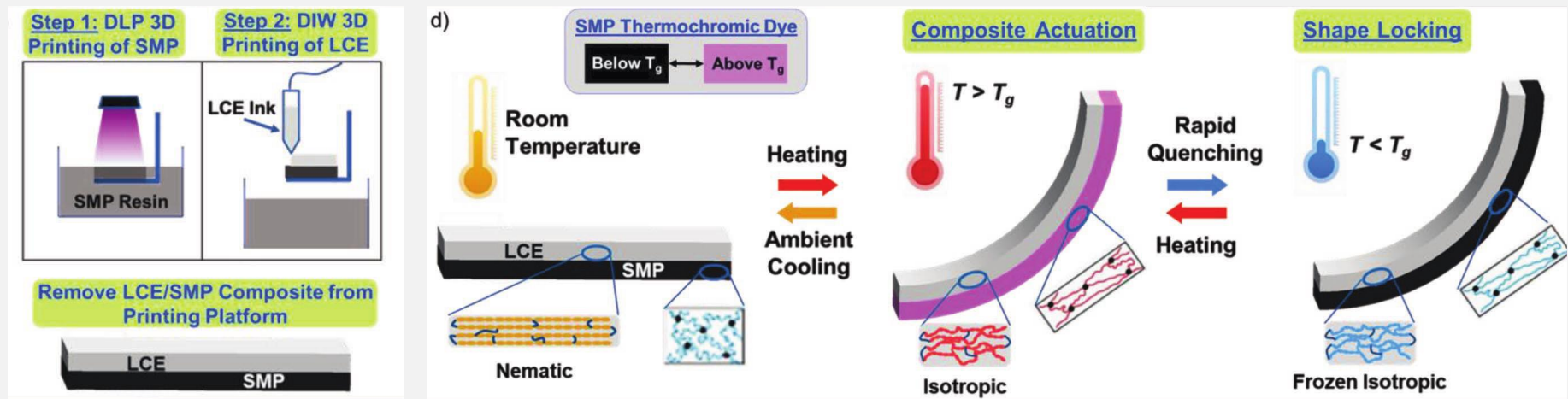
UV curing system



Print heads



Open-source 3D printer



4D Printed Multifunctional Composites with Tunable Shape Morphing

LCE-SMP Load Supporting Composite

Devin J. Roach¹, Xiaohao Sun¹, Xirui Peng¹, Frédéric Demoly², Kun Zhou³, H. Jerry Qi^{1*}

¹Georgia Institute of Technology

²Univ. Bourgogne Franche-Comté

³Nanyang Technological University

4D Printed Multifunctional Composites with Tunable Shape Morphing

Reconfigurable Wrench using LCE-SMP

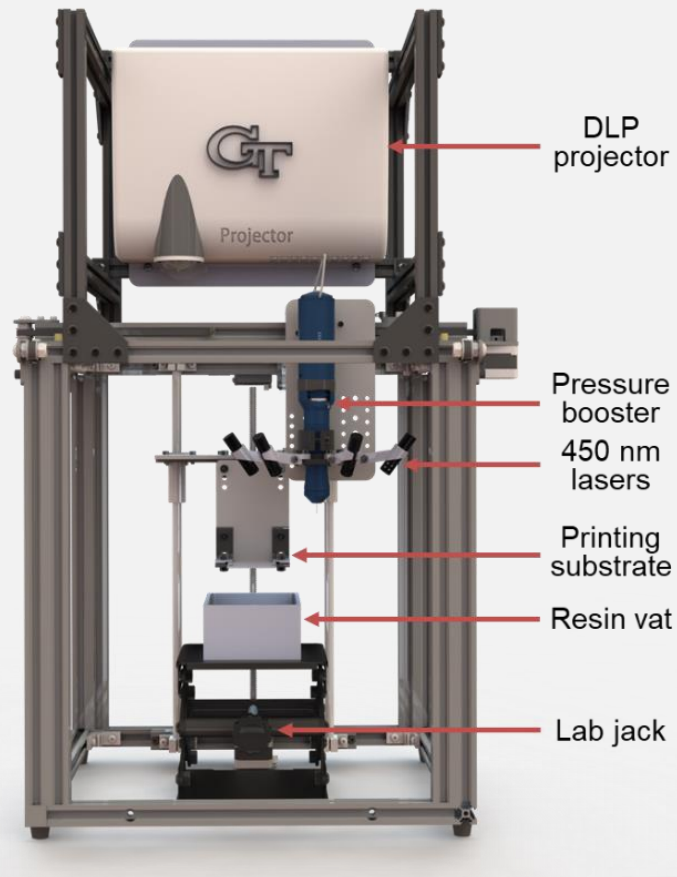
Devin J. Roach¹, Xiaohao Sun¹, Xirui Peng¹, Frédéric Demoly², Kun Zhou³, H. Jerry Qi^{1*}

¹Georgia Institute of Technology

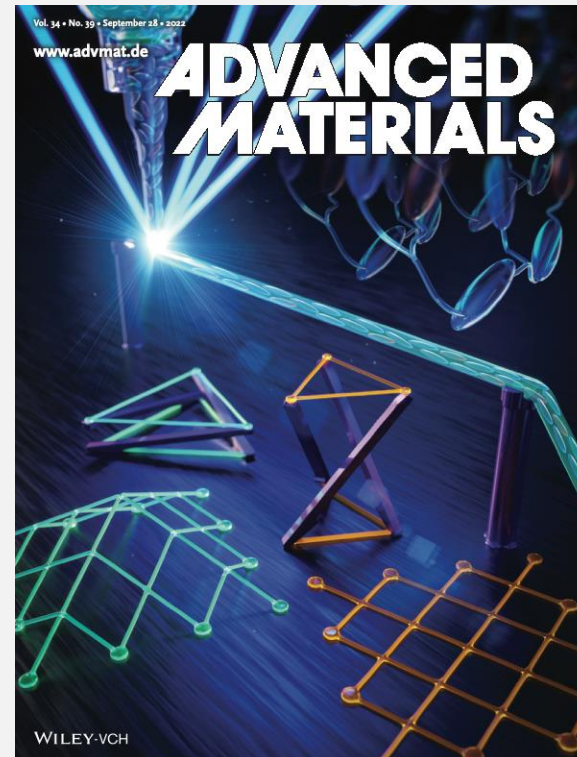
²Univ. Bourgogne Franche-Comté

³Nanyang Technological University

[Roach et al., 2022]



[Peng et al., 2022, *Advanced Materials*]



4D Printing of Freestanding Liquid Crystal Elastomers via Laser-assisted Hybrid Additive Manufacturing

Printing and actuation of the hybrid cuboid lattice

Xirui Peng^{1§}, Shuai Wu^{2§}, Xiaohao Sun¹, Liang Yue¹, S. Macrae Montgomery¹, Frédéric Demoly³, Kun Zhou⁴, Ruikun Renee Zhao^{2*}, H. Jerry Qi^{1*}

¹Georgia Institute of Technology, USA

²Stanford University, Stanford, USA

³Univ. Bourgogne Franche-Comté, France

⁴Nanyang Technological University, Singapore

4D Printing of Freestanding Liquid Crystal Elastomers via Laser-assisted Hybrid Additive Manufacturing

Printing and actuation of the actuator with tunable stability

Xirui Peng^{1§}, Shuai Wu^{2§}, Xiaohao Sun¹, Liang Yue¹, S. Macrae Montgomery¹, Frédéric Demoly³, Kun Zhou⁴, Ruikun Renee Zhao^{2*}, H. Jerry Qi^{1*}

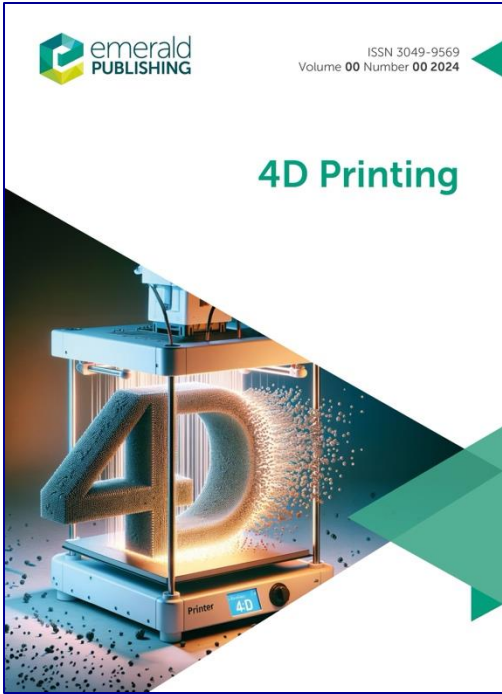
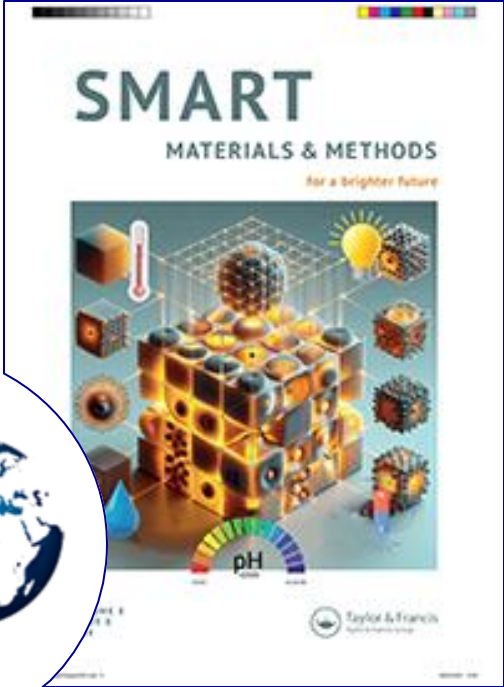
¹Georgia Institute of Technology, USA

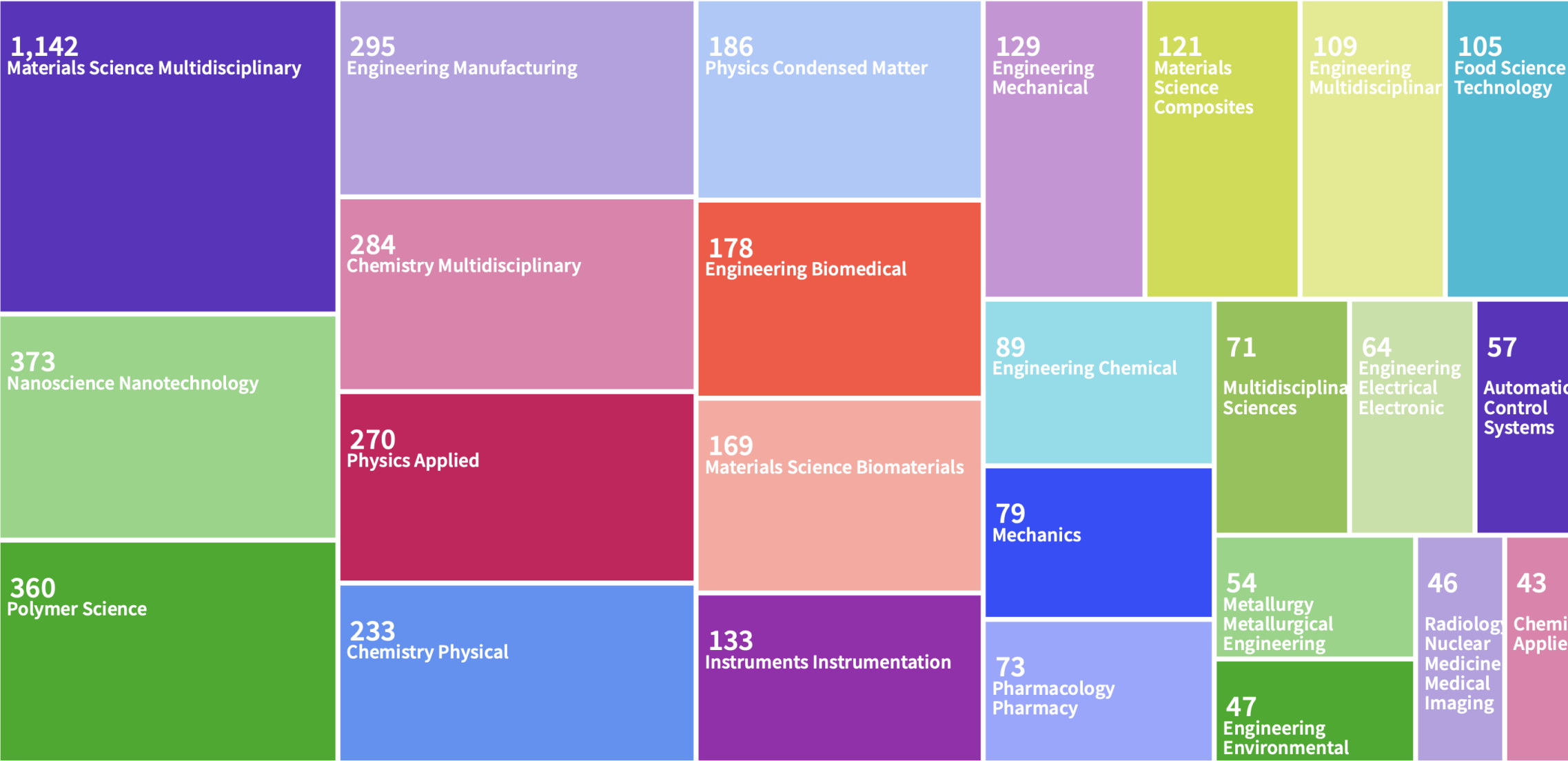
²Stanford University, Stanford, USA

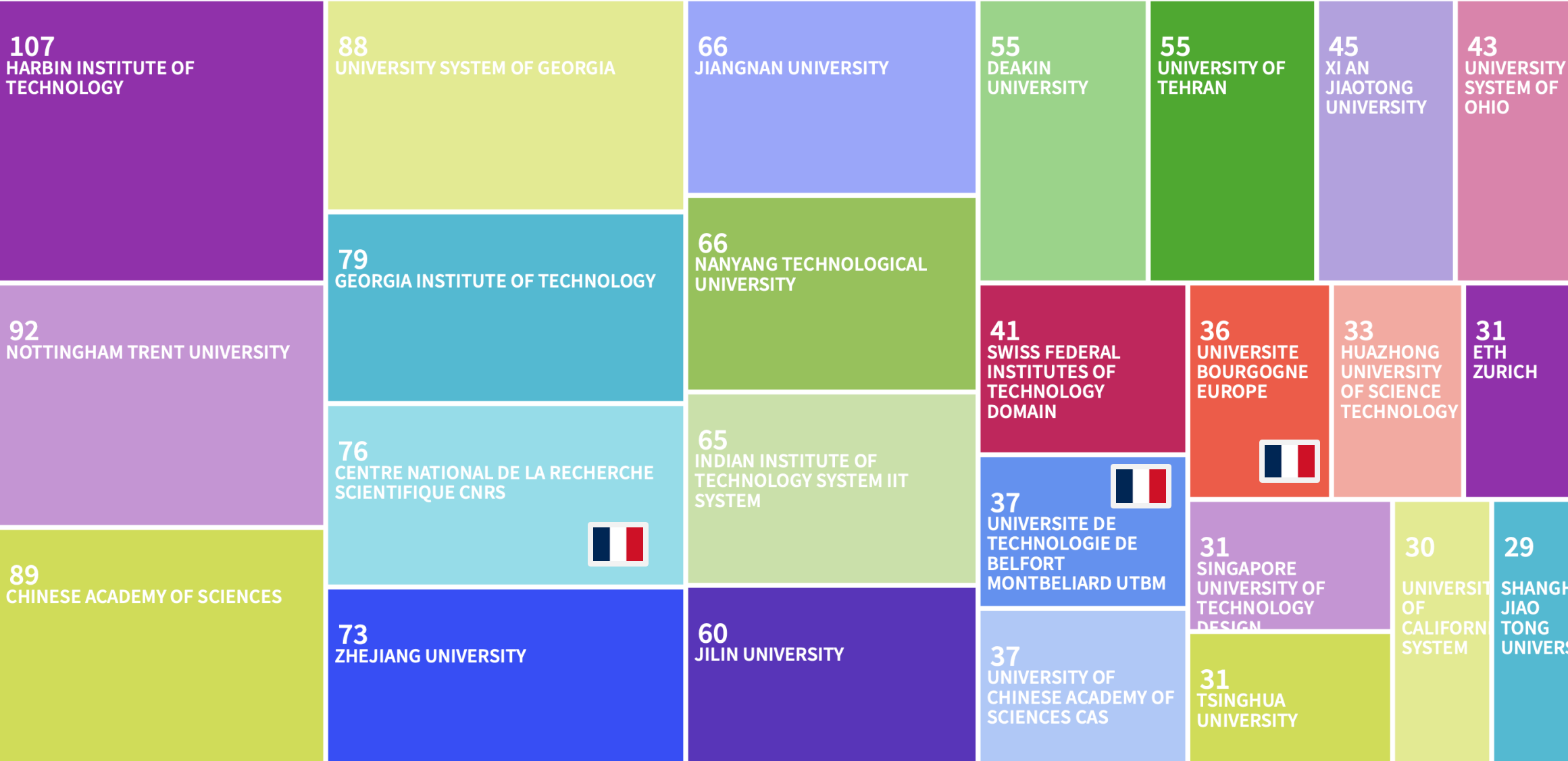
³Univ. Bourgogne Franche-Comté, France

⁴Nanyang Technological University, Singapore

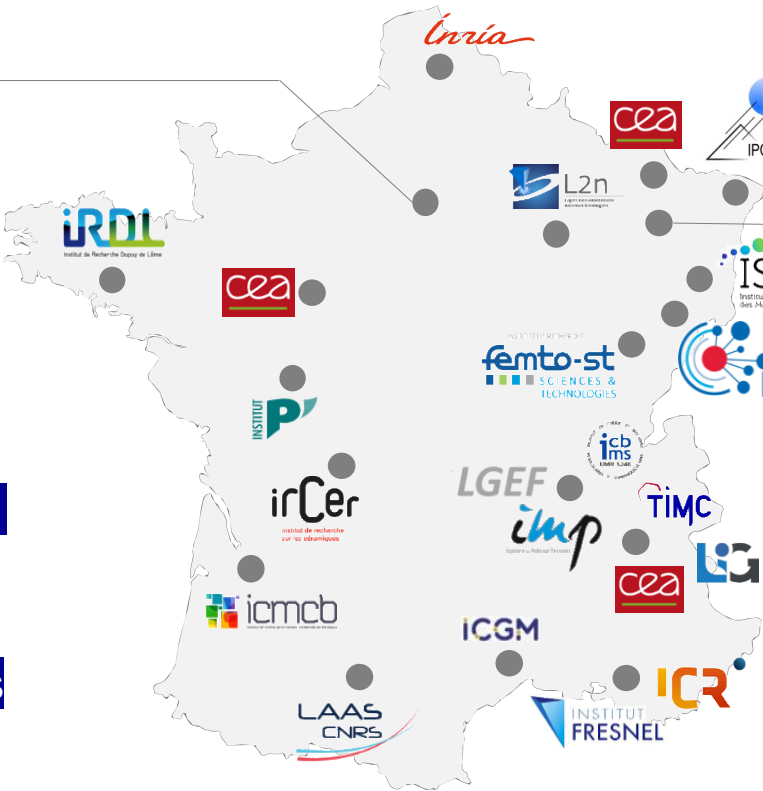
MEMBRES FONDATEURS







Matériaux intelligents et structures transformables
par impression 4D



CONVERGENCE DES SCIENCES

- Science des matériaux
- Génie des procédés
- Ingénierie
- Physique
- Chimie
- SHS



1ères journées du GDR
6-7 novembre 2025
UTBM Belfort
SAVE THE DATE

OBJECTIFS

- Exploration & découverte de matériaux actifs et de structures
- Imprimabilité
- Performances des matériaux/structures
- Démonstrateurs



<https://gdr-trans4m.utbm.fr>



CONCEPTION ET IMPRESSION 4D MULTI-MATERIAUX

Frédéric DEMOLY

Professeur des Universités

Membre Junior de l'Institut universitaire de France



RDM
RÉSEAU DES MÉCANICIENS

