New developments in topology optimization

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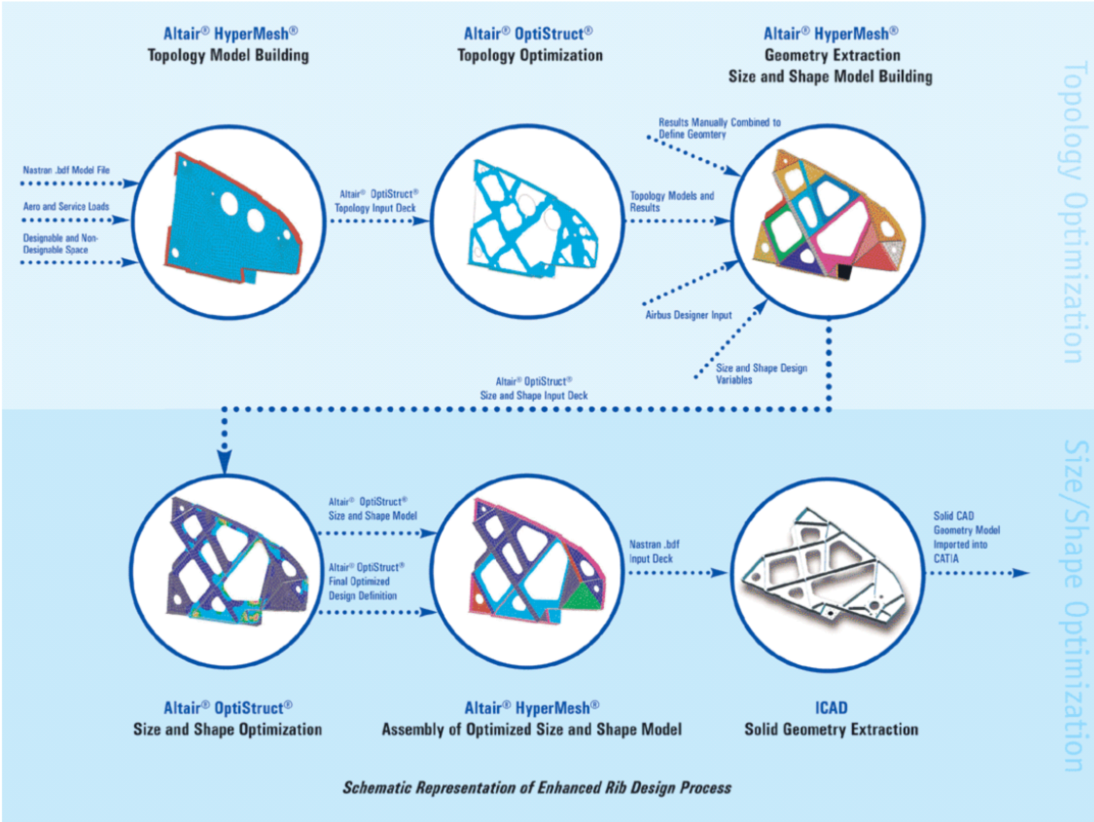
Based on V. Bhat's work (Msc)

1.General introduction on topology optimization

2. ALM based projection
3. Conclusion and future works

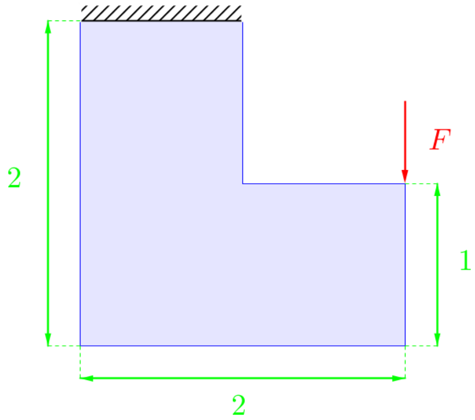
INDUSTRIAL PROCESS

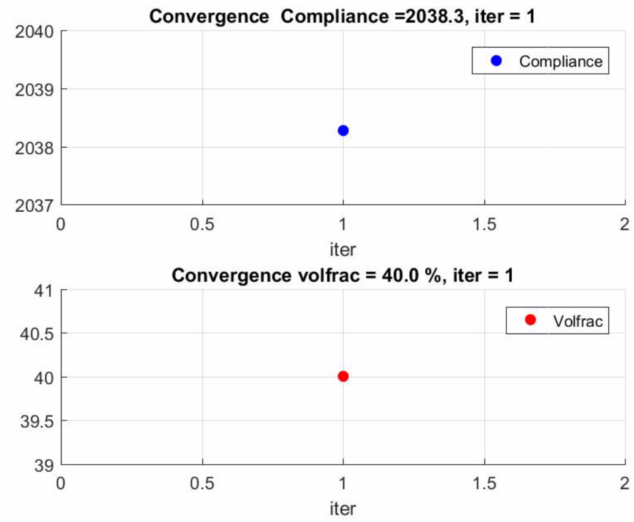
"The art of structure is where to put the holes."
~Robert Le Ricolais
(1894-1977)

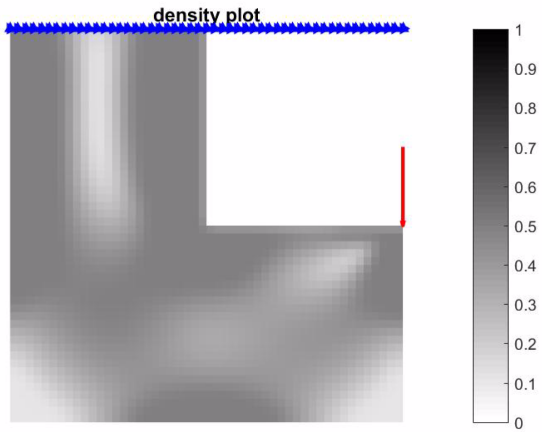


Altair Engineering

Results SIMP nelx=nely=40→ 1600 design variables minC st Volfrac=0.25 , Ku=f







Andreassen, E., Clausen, A., Schevenels, M., Lazarov, B. S., & Sigmund, O. (2011). Efficient topology optimization in MATLAB using 88 lines of code. Structural and Multidisciplinary Optimization, 43(1), 1-16.

http://www.topopt.mek.dtu.dk

Intuitive Problem? Quadratic Form

- Objective function: Strain energy

$$\min c(\mathbf{x}) = \mathbf{U}^T\mathbf{F} = \mathbf{U}^T\mathbf{K}\mathbf{U}$$

with $\mathbf{K} = \mathbf{K}_0 \sum_{e=1}^{N} x_e^p$

$x_e = \dfrac{\rho_e}{\rho_0}$ with one can write: (4)

Transform discrete variables continuously
(TO USE gradient-based algorithms)
Cheap derivatives!

$$\min c(\mathbf{x}) = \sum_{e=1}^{N} (x_e)^p \mathbf{u}_e^T \mathbf{k}_0 \mathbf{u}_e \qquad (5)$$

- Contraints: mass target

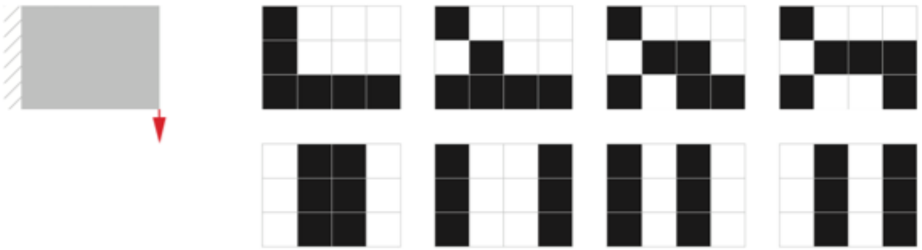
$$\frac{V(\mathbf{x})}{V_0} = f = const \quad \Leftrightarrow \quad \sum_{e=1}^{N} V_e x_e - V_0 f = 0 = h(\mathbf{x})$$

$$0 < \rho_{\min} \leq \rho_e \leq 1$$

$$\frac{\partial c}{\partial \rho_e} = -p(\rho_e)^{p-1}\mathbf{u}_e^T \mathbf{k}_0 \mathbf{u}_e$$

Pixels

- Finding a solution by checking all the possible combinations IS impossible since the number of topologies nT increases exponentially with the number of finite elements n
- nT = 2^n,



The legal (top) and some illegal (bottom) topologies with 4 by 3 elements

Division into elements (pixels or voxels) and binary decision for each
or example 10,000 elements --> 210,000 possible configurations!

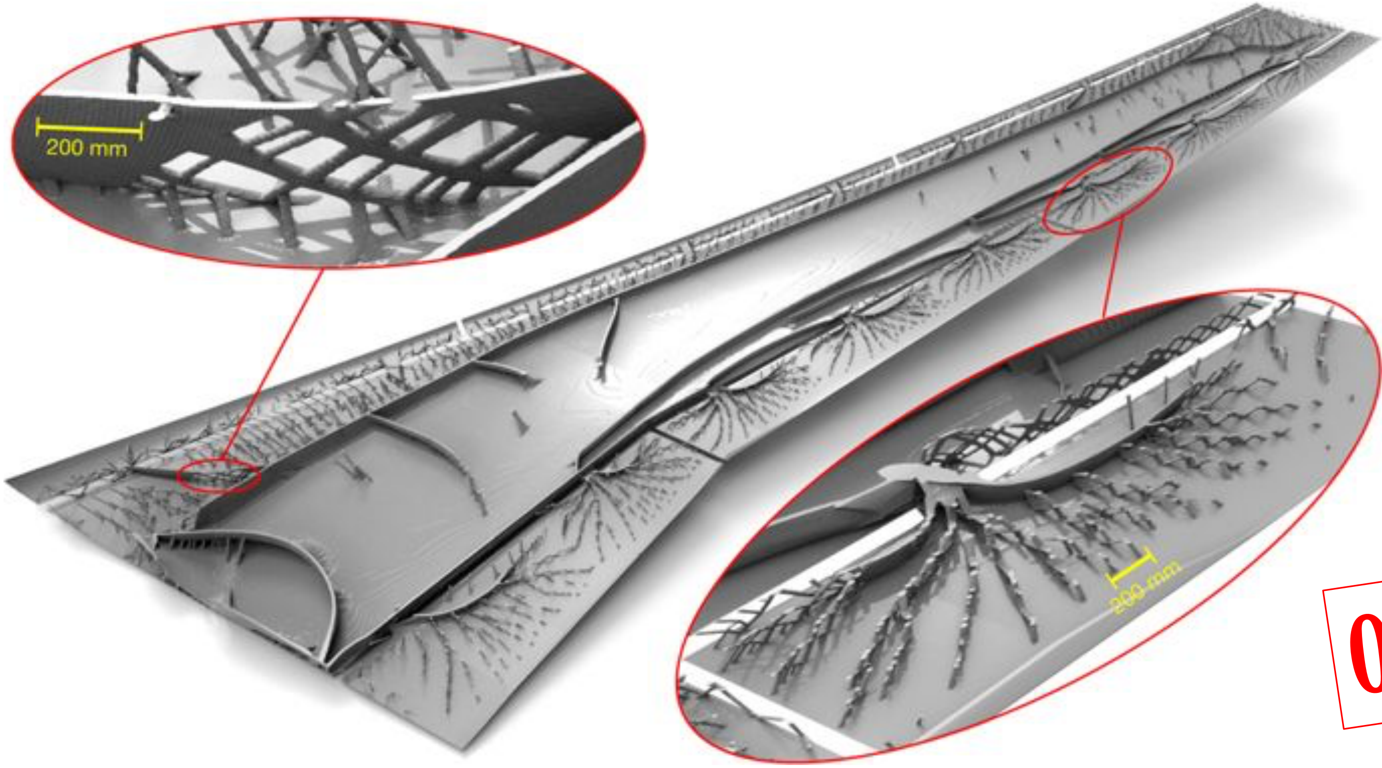
Pixels?

When the size of the FE model is increasing, the SIMP optimization problem is ... increasing

Chris Columbus et al, Pixels, movie 2015

Use HPC and lot of time

Niels Aage, Erik Andreassen, Boyan S Lazarov, and Ole Sigmund. Giga-voxel computational morphogenesis for structural design. Nature, 550(7674):84, 2017.



Or ...

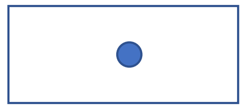
Moving Node Approach (MNA)

6 variables per node

G. Raze, M. Charlotte, J.Morlier, Vers la reconnaissance d'éléments structuraux, CSMA, 2017
J. Overvelde, PHD thesis, TU Delft, 2012

Optimization variables :

- Positions (x,y)
- Orientation (θ)
- Dimensions (Lx,Ly)
- Mass (M)



Structural Members engineering bricks like: beam, plate, geometric primitives

Moving Node Approach (MNA)
Projection

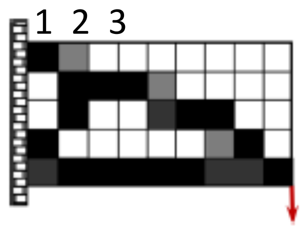
Design variables update → Interpretation → Model update Density, Young modulus

SIMP

Implicit framework

variables : material density

$x_1 = 1$
$x_2 = 0.5$
$x_3 = 0$
...

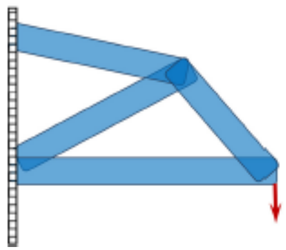


Innovative approach to help engineering solution identification :
Components are placed in design space according to variables and material density are derived accordingly.

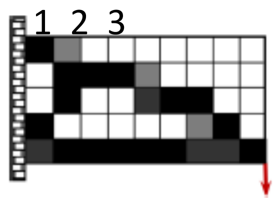
Explicit framework

Variables : geometrical data

$x_1 = Position$
$x_2 = Length, Height$ ...



Projection

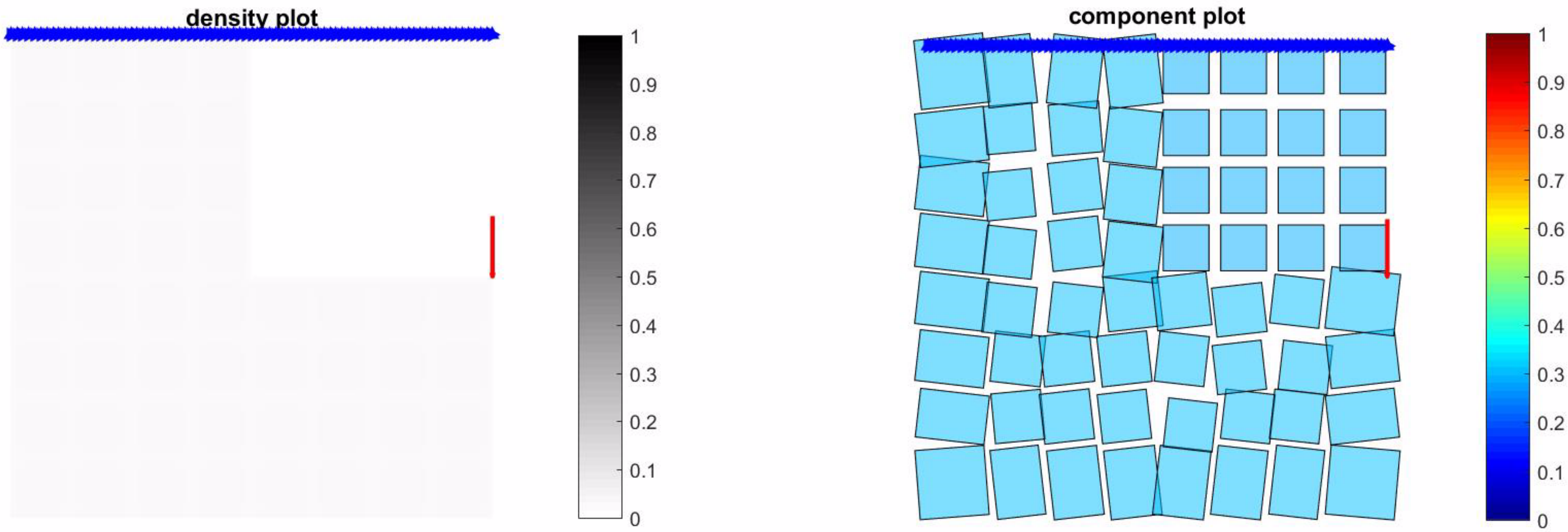


(GUO et al. 2015) A new topology optimization approach based on Moving Morphable Components (MMC) and the ersatz material model

Design is made of engineering bricks like: beam, plate, brick….

Results MNA, 8*8*6=384 design variables
minC st Volfrac=0,4

At the end, explicit assembly of components!



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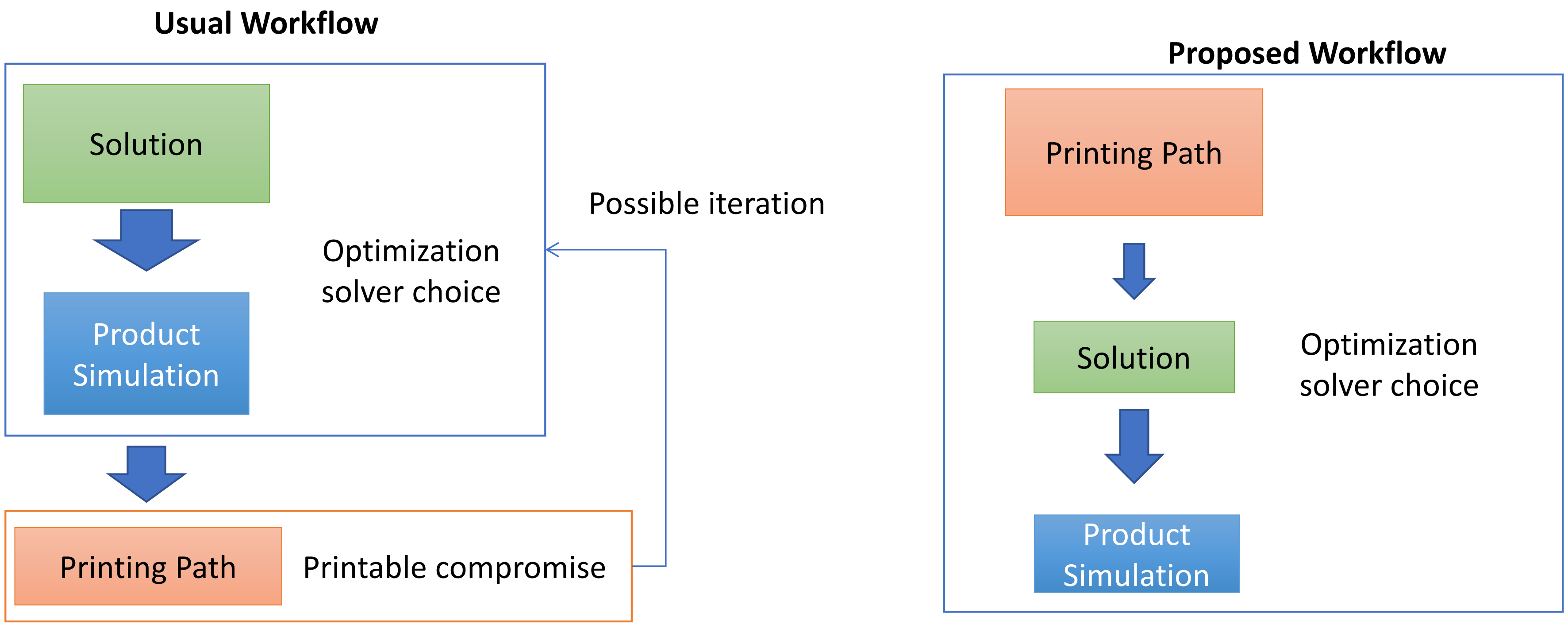
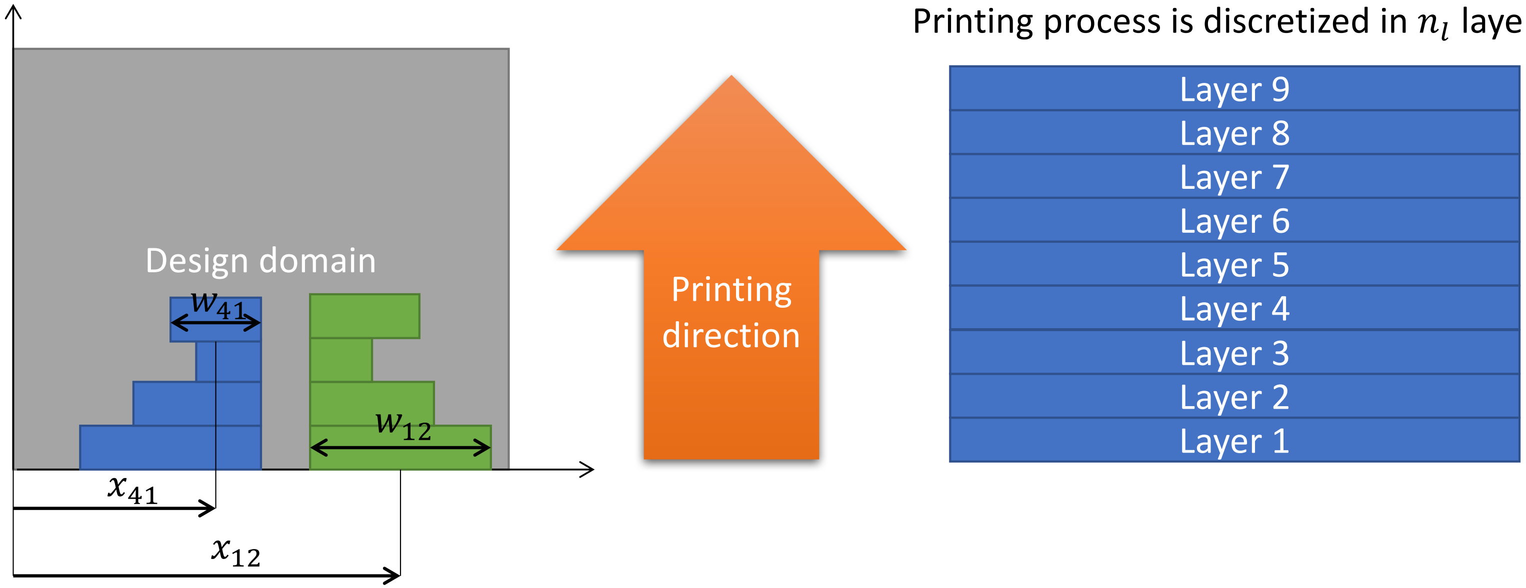
ALM based projection



ALM based projection

A solution is determined by its manufacturing process: (in this case printing path)

Printing process is discretized in n_l layers



- MNA Components are replaced by printed branches
- Design variables will be printed branch position and width per layer: x_{li}, w_{li}
- For each layer a projection is made to get the solid model modulus

ALM based projection

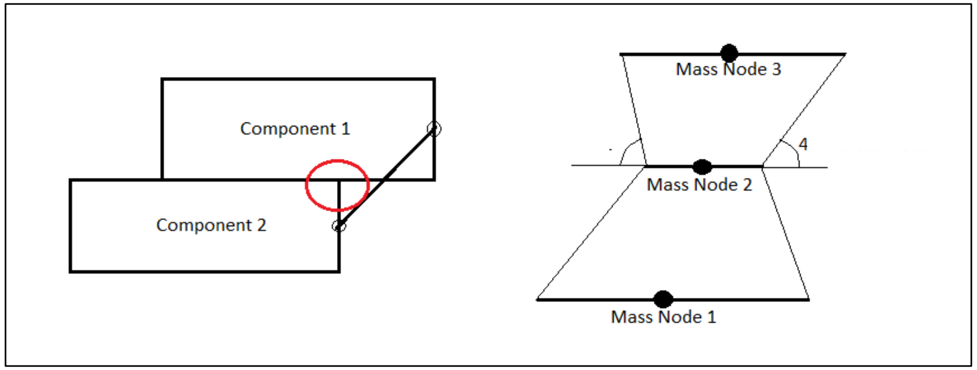
Optimization formulation

$$
\begin{cases}
\min\limits_{X} c = F^T \cdot U \\
\qquad s.t. \\
\sum\limits_{i=1}^{N} \rho_i - v_f N \leq 0 \\
\theta_l \leq \theta \quad \leq \pi - \theta_l
\end{cases}
$$

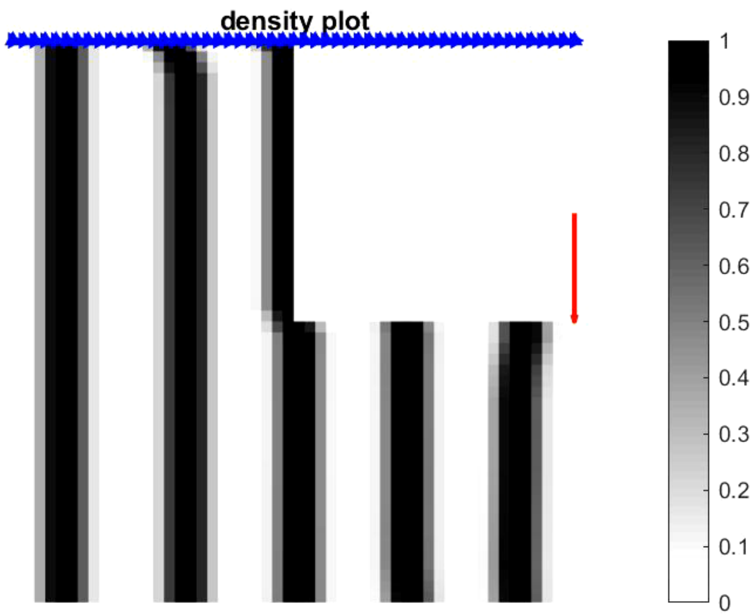
External forces work

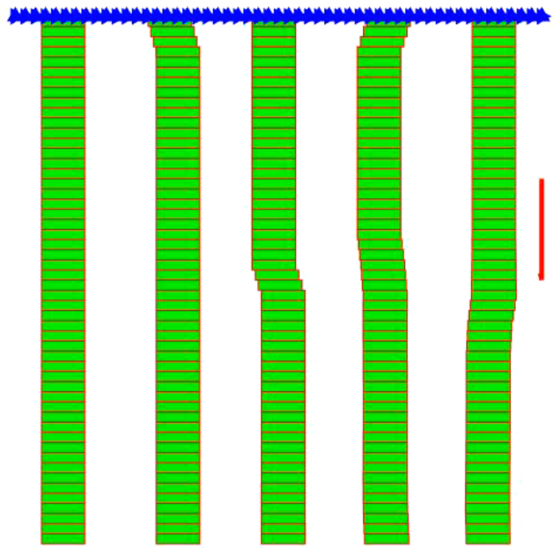
Mass constraint

Overhang angle constraint



ALM based projection





$N_x = N_y = 52$
$v_f = 0.4$
$5\ printing\ components$
$18\ printing\ intervals$
$5{\times}18{\times}2\ design\ variables$

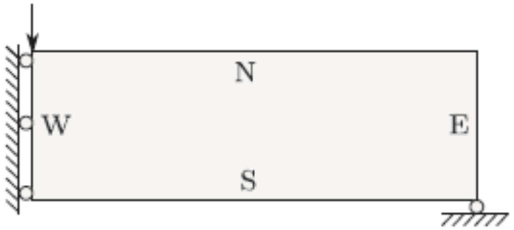
3. Conclusion and future works

Conclusion

- A new framework has been released fully compatible with FDM (Fuse Deposition Modeling)
- Overhang angle constraints was succesfully enforced in the optimization loop
- The solution is described by an explicit trajectory
- We are ready to adapt our methodology with others ALM processes

Future works (1)

- Ongoing works→ comparison with Amfliter



Langelaar, M. (2017). An additive manufacturing filter for topology optimization of print-ready designs. Structural and multidisciplinary optimization, 55(3), 871-883

a) N case: $C/C_{ref} = 111\%$, $M_{nd}=21.7\%$

b) E case: $C/C_{ref} = 101\%$, $M_{nd}=14.0\%$

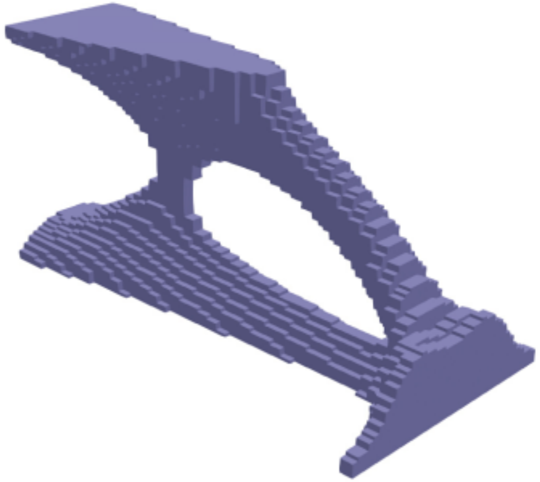
c) S case: $C/C_{ref} = 106\%$, $M_{nd}=18.1\%$

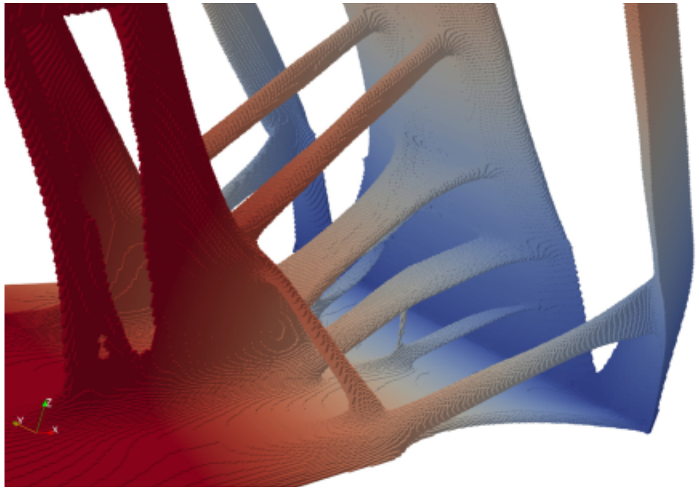
d) W case: $C/C_{ref} = 100.0\%$, $M_{nd}=12.7\%$

e) Reference case (unrestricted): $C = C_{ref}$, $M_{nd}=14.8\%$

Future works (2)

- HPC using PetsC

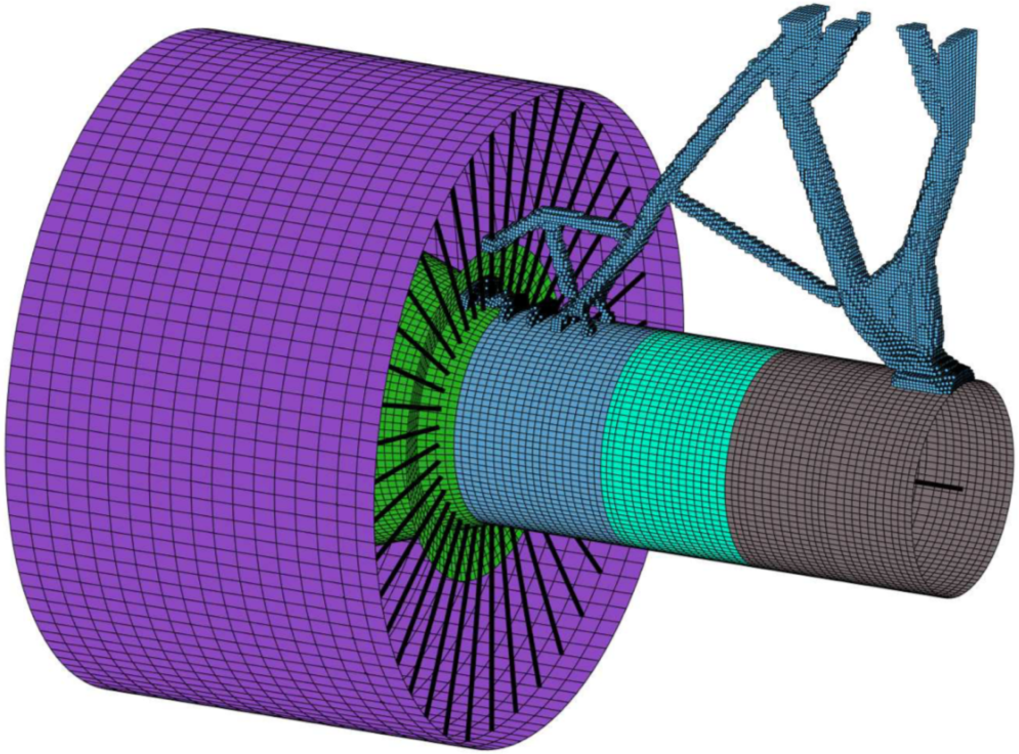




Low resolution SIMP(~0,1 million d'éléments) on CALMIP cluster

Structural detailed (~87 million of elements)

My PhD thesis→ innovative pylon or morphing airfoil



Papers & conf on this topic

Thanks !!

Coniglio, S., Gogu, C., Amargier, R., & Morlier, J. (2017, June). Pylon and engine mounts performance driven structural topology optimization. In World Congress of Structural and Multidisciplinary Optimisation (pp. 1349-1363). Springer, Cham.

Coniglio, S., Gogu, C., & Morlier, J. (2018). Weighted Average Continuity Approach and Moment Correction: New Strategies for Non-consistent Mesh Projection in Structural Mechanics. Archives of Computational Methods in Engineering, 1-29.

Coniglio, S., Morlier, J., Gogu, C., & Amargier, R. (2018). Original Pylon Architecture Design Using 3D HPC Topology Optimization. In 2018 AIAA/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference (p. 1388).

G. Raze et al, Optimisation topologique sans maillage : vers la reconnaissance d'éléments structuraux, CSMA 2017

Several Papers in preparation

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