Developments in Topology Optimization for Additive Manufacturing

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Outline

- Introduction to topology optimization
- Link with AM: potential & challenges
- Current developments
- Conclusions
Topology optimization: generating the best material distribution

What shape to use?  Where to place material?

bracket

post-processed final design
1. **Define** problem:
   - Objective, constraints
   - Domain, boundary conditions
   - Loadcases

2. **Discretize** and parameterize material distribution

3. **Optimize** material distribution for best performance

4. **Evaluate** / fine-tune result (postprocessing, shape optimization)

Maximize stiffness
Use only 50% material
Topology optimization loop

New
Values of the density variables

New
Component analysis (FEA)

New
Values of the objective and constraints

New
Gradient information (design sensitivity)

Optimization algorithm
Topology optimization characteristics

Strengths

• Little designer input needed
• High potential to find radically new designs
• Systematic way to solve complex design problems

Challenges

• Optimized geometries complex: conventional fabrication difficult
• Post-processing often needed
• Link to other CAD tools underdeveloped
Uniform temperature increase
Topology optimization & 3D printing synergy

- **3D printing** enables realization of full benefits of **topology optimization**
  - ‘Complexity for free’
  - Much less re-engineering needed
  - Optimal performance remains intact
Topology optimization & 3D printing synergy

- Topology optimization enables realization of full benefits of 3D printing
  - Generate designs that fully exploit 3D printing potential
  - Create tailor-made optimized parts
  - Reduce design iterations, improve time-to-market
Status: maturing design technology

- Commercial software available
- Successfully adopted in industry
- Developments towards more complex design problems
- Shift from conceptual design to final design
- Demand for *print-ready* designs
Print-ready topology optimization: Challenges

- **AM design constraints**
  - Feature size
  - **Overhang angle**

- Minimize **costs due to supports**
  - Suitable design
  - Best build orientation
  - Facilitate easy removal

- Control local **material quality**
  - Process modeling
  - Microstructure prediction
Overhang angle limitation:
Post-processing of designs

Leary et al. 2014
Support structures vs. Post-processing

- Part volume: 48 cm$^3$
- Support: 42 cm$^3$
- Build time: 5.7 h

- Part volume: 55 cm$^3$
- Support: 0 cm$^3$
- Build time: 2.6 h

Leary et al. 2014
Overhang angle limitation: Adding permanent lattice structures

- Lattice acts as support structure
- Remains functional part of component
- Challenge: quality control
Vision:
include overhang constraints in optimization

Mesh-based

Boundary-based

Airbus
Defence & Space

Reuben Serphos

NLR
Emiel van der Ven

TUDelft
Mesh-based overhang constraints

- Effective in removing overhang
- Costly additional computations
- Limited to 45° overhang angle

Overhang detection

With constraint: overhang-free design
Boundary-based overhang constraints

- Effective in enforcing boundary orientation limits
- Applies to any overhang angle
- Generates “free-standing” points
Status

- Partial success in enforcing overhang constraints, further development needed

- Next challenges:
  - Including small overhanging sections
  - Extending to 3D
  - Including build orientation

- End goal: Including all relevant process information
Topology optimization

Values of the density variables

Component analysis (FEA)

Optimization algorithm

Gradient information

Values of the objective and constraints
Topology optimization for print-ready designs

Build information → Printing process simulation → Gradient information → Optimization algorithm

Component analysis (FEA) → Values of the objective and constraints

TU Delft
Process modeling

Khairallah et al, 2014

Marius Knol, Can Ayas
Conclusions

• Synergy between topology optimization & AM
• Specific constraints required
• Progress on overhang constraints

• Ultimately, integration of process simulation
• Development of AM process models for design: key aspect
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