AACHEN CENTER FOR ADDITIVE MANUFACTURING

dap Digital Additive Production | RWTH AACHEN UNIVERSITY


ACAM

Additively Manufactured 3D Connection Elements for more Sustainability in the Construction Industry

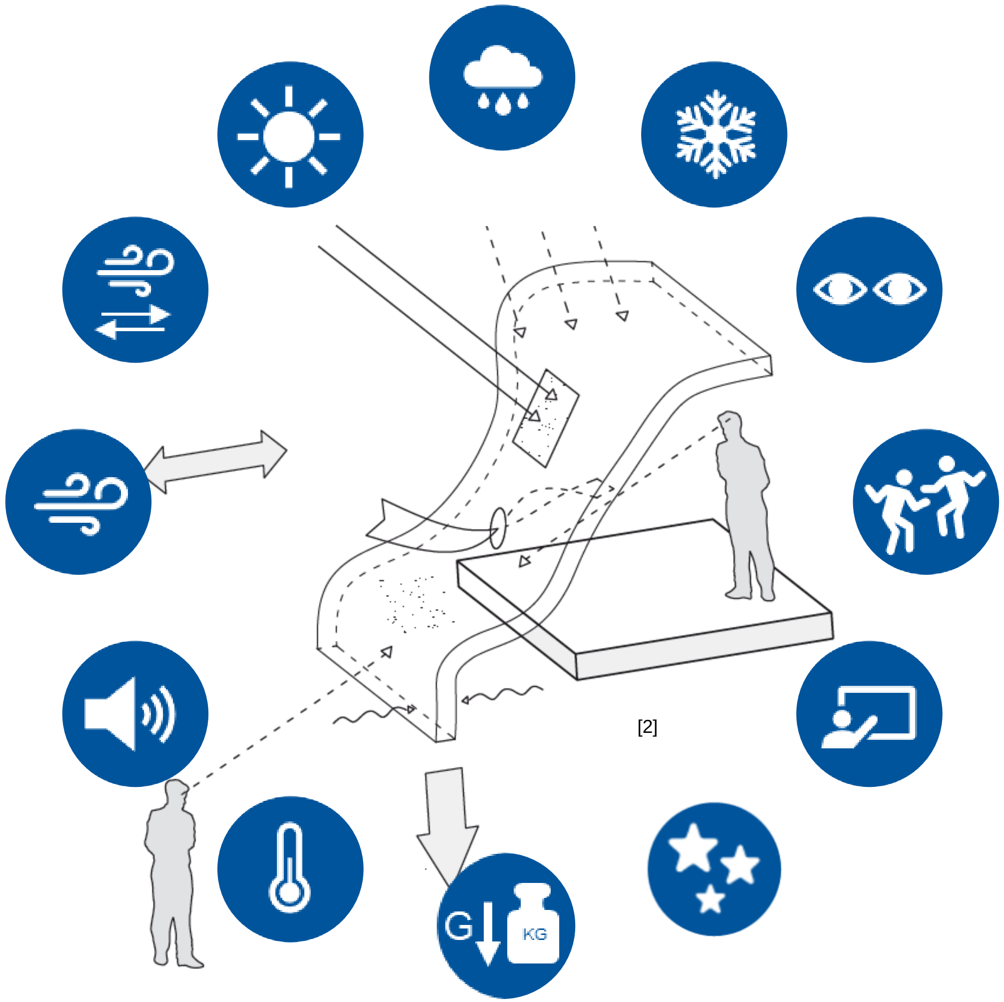
Joana Schulte, Omid Zarei | 27.09.2022

Introduction
Environmental Impact of the Building Industry

- **Building sector** is considered the worlds biggest contributor to the worlds global energy consumption and greenhouse gas emissions
- In 2019 the construction and operation of buildings contributed to
  - 35 % of the total energy consumption [1]
  - 38 % of the energy-related CO_2 emissions [1]
- One of the **Key Industries** for a more sustainable future by reducing:
  - Global energy demand
  - Greenhouse gases

[1] United Nations Environment Programme (2020): 2020 Global Status Report for Buildings and Construction: Towards a Zero-emission, Efficient and Resilient Buildings and Construction Sector

Introduction
Façades – Requirements & Loads



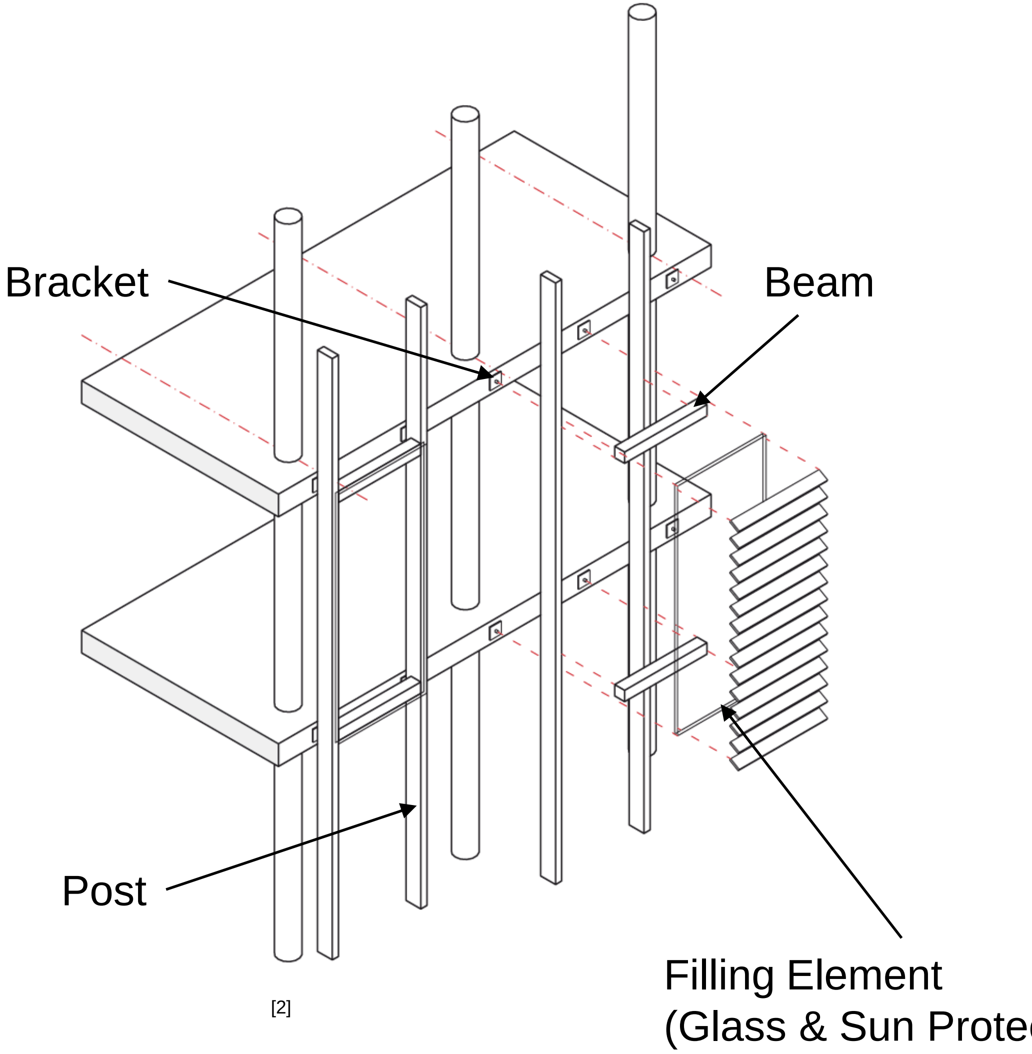
[2]

Requirements & Loads

- Wind load
- Self-weight
- Insulation
- Live load
- Snow-weight
- Sun protection
- View in / View out
- Protection from rain
- Ventilation
- User comfort
- Sound
- Appearance

[2] Knaack, Ulrich; Auer, Thomas; Bilow, Marcel; Klein, Tillmann (2007): Facades. Principles of Construction

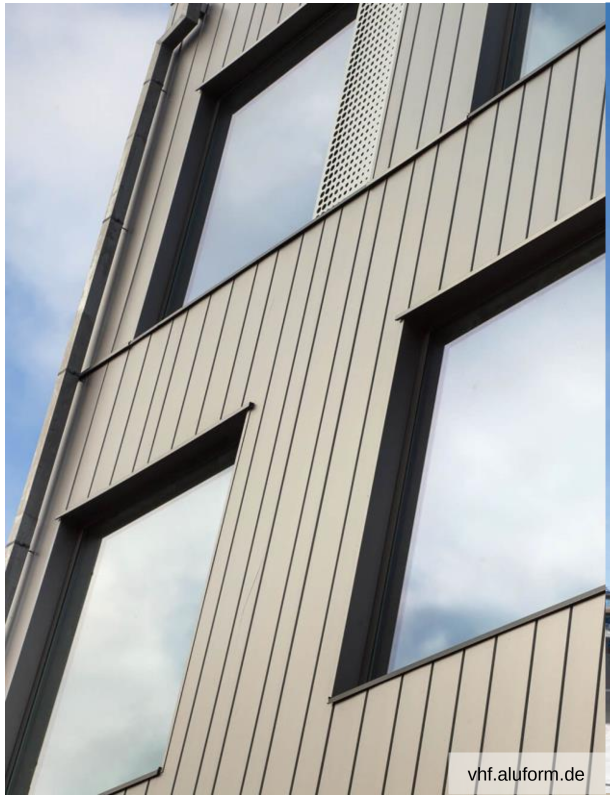
Systemized Façade Systems
Post and Beam Façades

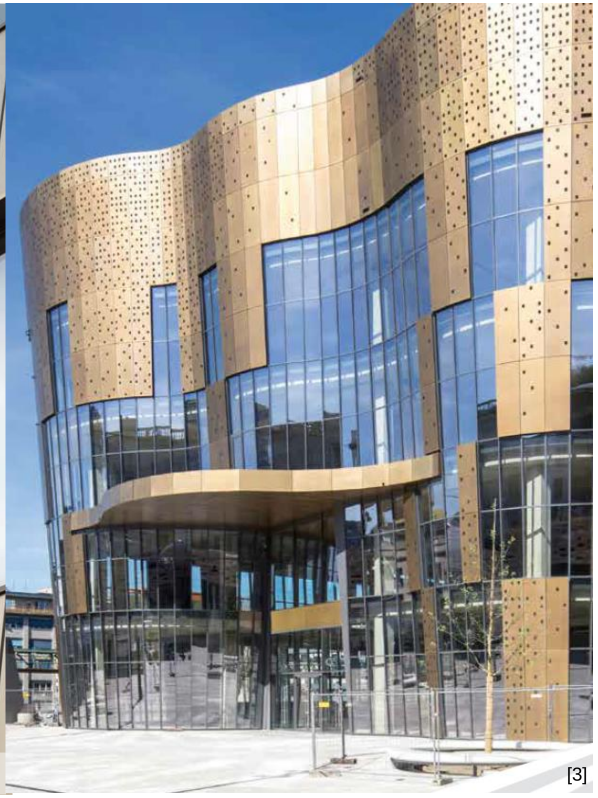


[2]

[2] Knaack, Ulrich; Auer, Thomas; Bilow, Marcel; Klein, Tillmann (2007): Facades. Principles of Construction

Systemized Façade Systems
Rear Ventilated Façades


vhf.aluform.de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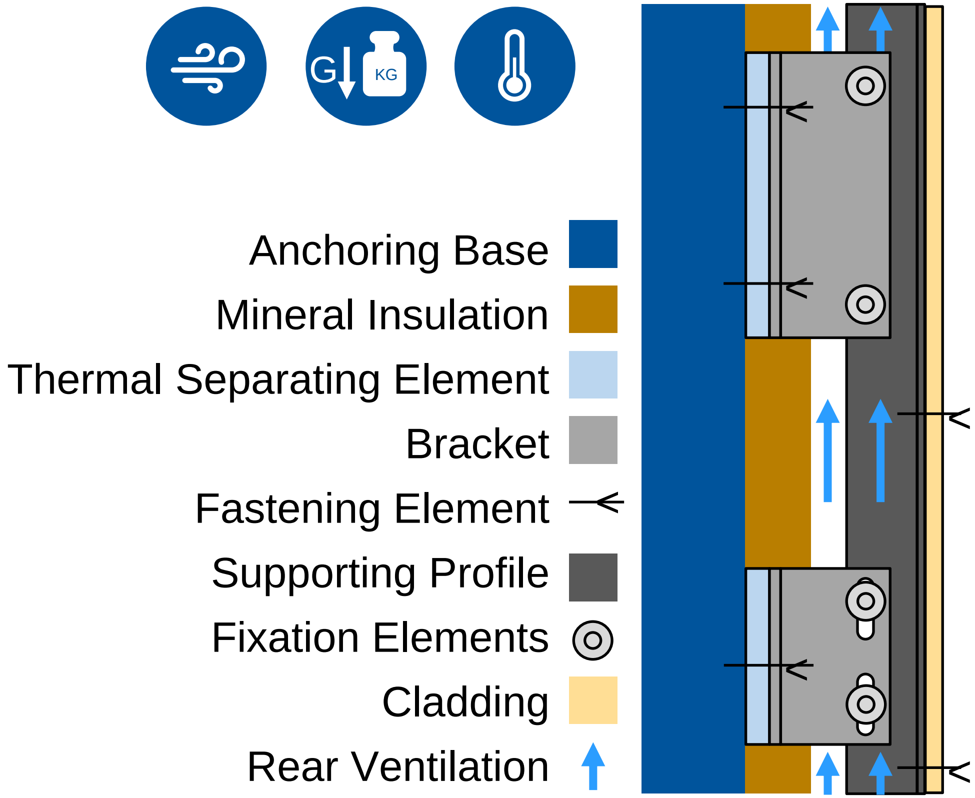
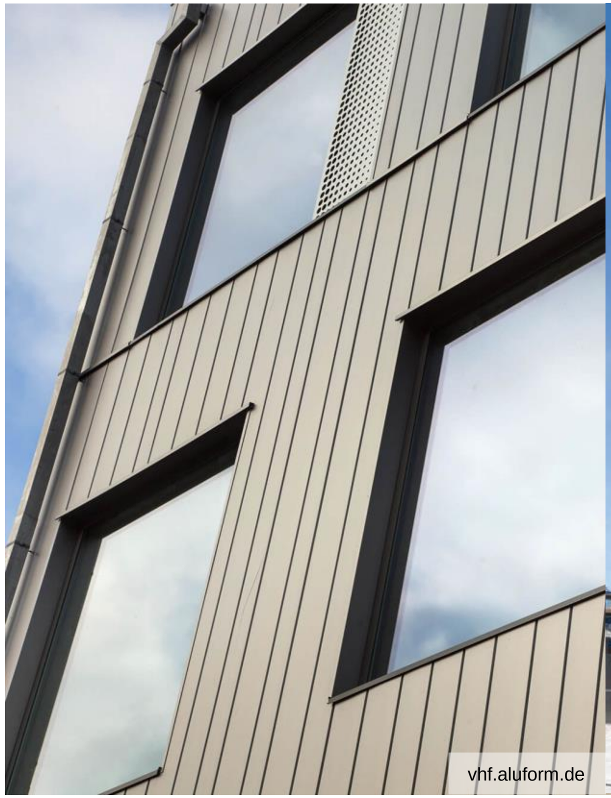


based on [3]

[3] Fachverband Baustoffe und Bauteile für vorgehängte hinterlüftete Fassaden e.V. - FVHF (2018): Innovationen auf dem roten Teppich

Systemized Façade Systems
Rear Ventilated Façades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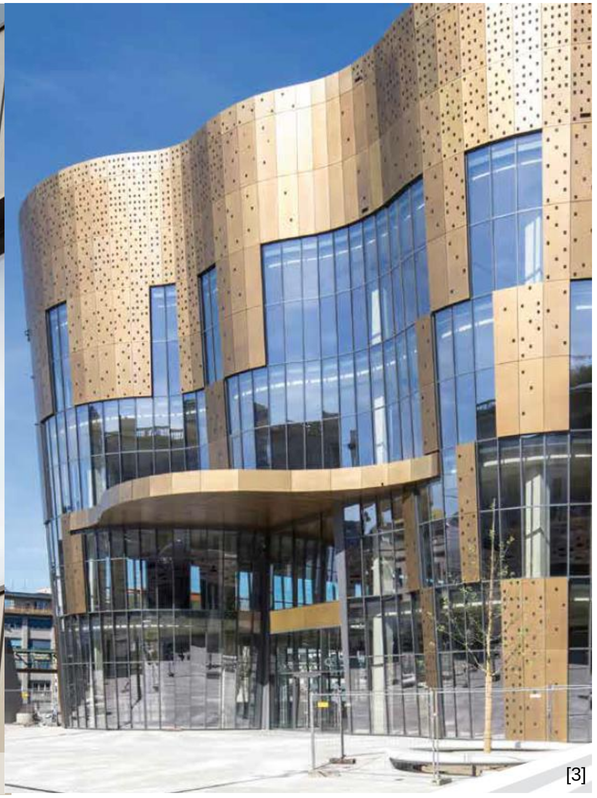

[3]

Dry walls
- Rear Ventilation
- Protection against condensation water

Short building time
- High degree of pre-fabrication / modularity
- Weather-independent assembly

Aesthetics & multifunctionality
- Combination of materials, surfaces, colors, shapes, joins
- Integration of photovoltaics or façade greening

Economical
- Long-lasting, highly durable, low maintenance
- Easy to disassemble, re-use and recycle

[3] Fachverband Baustoffe und Bauteile für vorgehängte hinterlüftete Fassaden e.V. - FVHF (2018): Innovationen auf dem roten Teppich

Façades

Challenges in Contemporary Façade Systems

Free-form façades


[4]

Risk for leakages

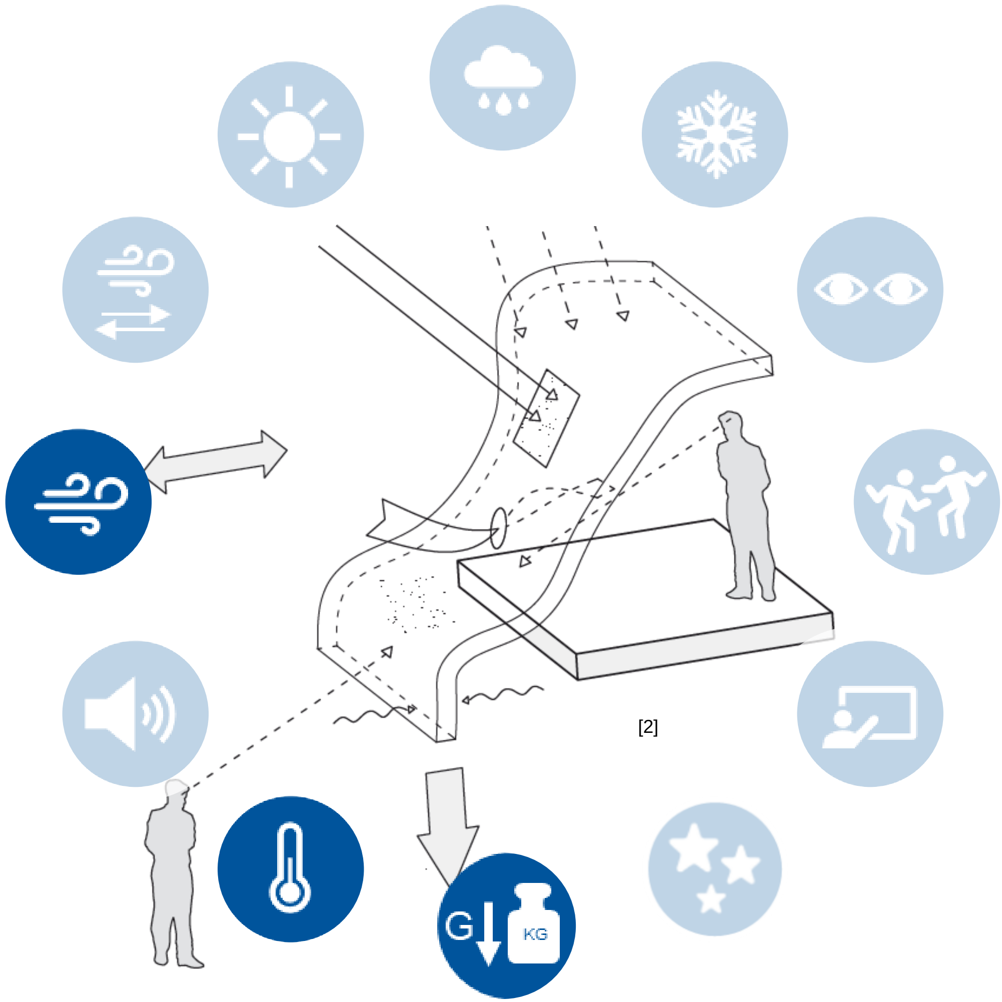

[4]

- Increasing demand for free-form façades
- Increased demands in terms of sealing and thermal transfer
- Intersections of façade systems are an area with high risk and high optimization potential
- All the different drainage, tightness and connection parts are joined in one spot
- Inaccuracies lead to leakages

[4] Strauß, Holger (2013): AM Envelope. The potential of Additive Manufacturing for façade construction

Façades

Requirements & Possible Improvements



Considered Requirements

- Wind load
- Self-weight
- Insulation

Targeted Improvements

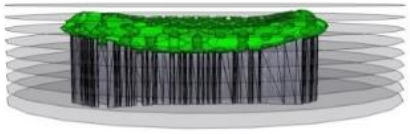
- Material reduction, lightweight engineering
- Thermal characteristics, energy consumption
- Recyclability, reusability

[2] Knaack, Ulrich; Auer, Thomas; Bilow, Marcel; Klein, Tillmann (2007): Facades. Principles of Construction

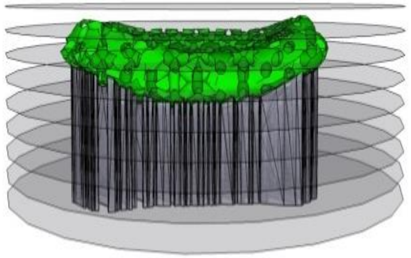
Introduction to AM

Laser Powder Bed Fusion

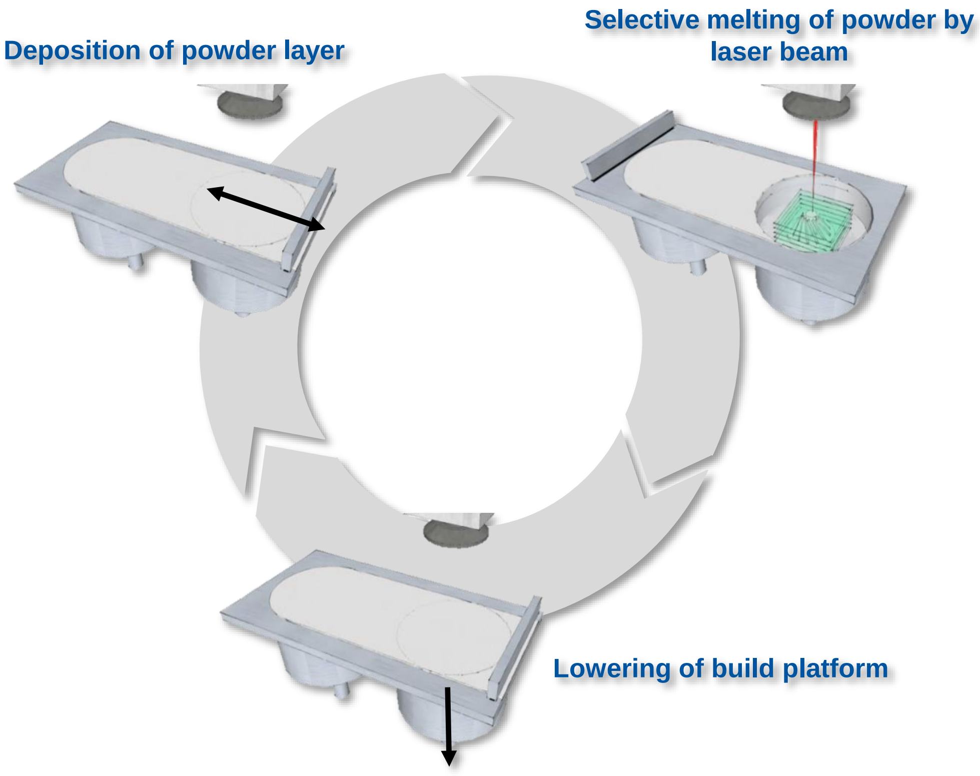
Pre-Process



Slicing

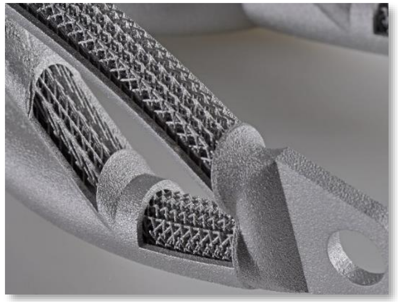


In-Process



Post-Process

Depowdering & removal from substrate



Final part with ultra-complex geometrical features

Introduction to AM
Typical Areas of Application

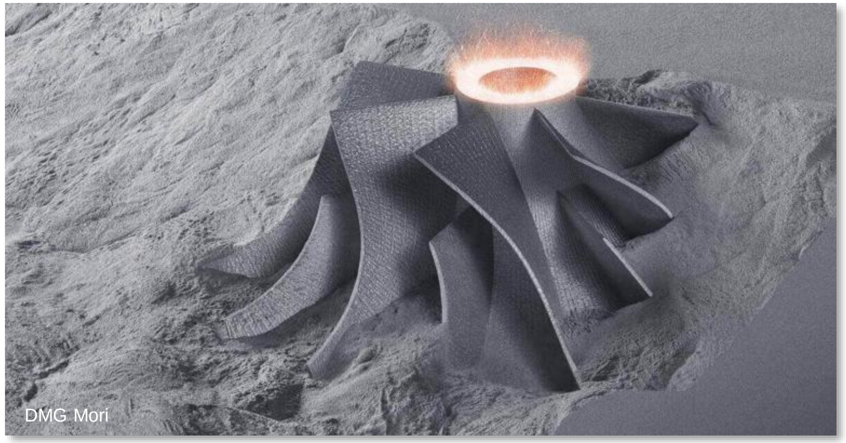
- Production on site
- Production on demand
- Prototyping
- Lightweight construction
- Reduction of iteration cycles in product development
- Small quantities and/or customer-specific products
- Production of spare parts for older serial products


APWorks


3d-grenzenlos.de


BEGO


Philipp Manger


DMG Mori

Source: Adapted from University Duisburg-Essen

Introduction to AM
Benefits and Barriers

AM Benefits

- **Design freedom**: Complex features, lightweight, monolithic
- **Flexible design** iterations and engineering changes
- **Integration of functions**
- **Tool-less** production
- Economic **small quantities** and **individualization**
- **Short time** and efficiency **idea to product**
- **Short supply chain**
- **Sustainability** by material reduction or efficiency in performance

AM Barriers

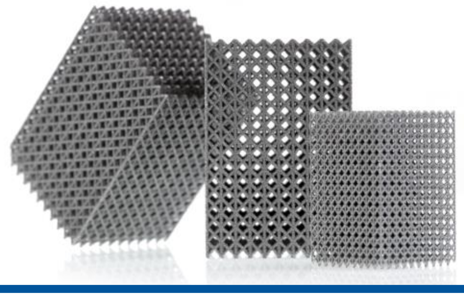
- **Long printing times**
- Almost **no economies of scale**
- **Low surface quality** as-built
- **Large geometrical tolerances** as-built
- Limited **component size**

Part Optimization for Increased Sustainability
Lightweight Design

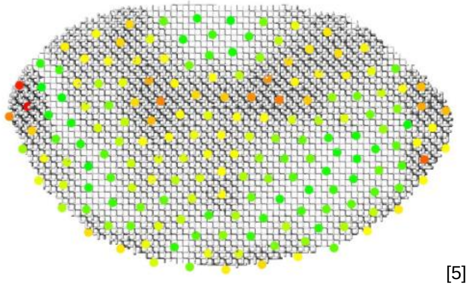
- Finding the optimal structure regarding a minimum weight while making optimum use of the material properties for the respective loading and boundary conditions
- Optimized material efficiency → saving on:
  - Material
  - Resources
  - CO_2 emissions
  - Cumulative energy
  - Costs

Structural Optimization

Lattice Structures

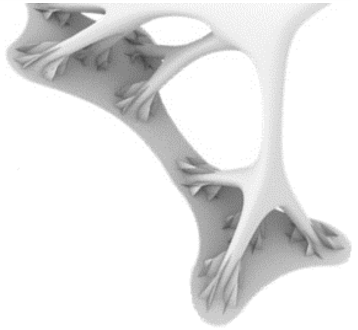


Digital Materials



[5]

Biomimetic Design

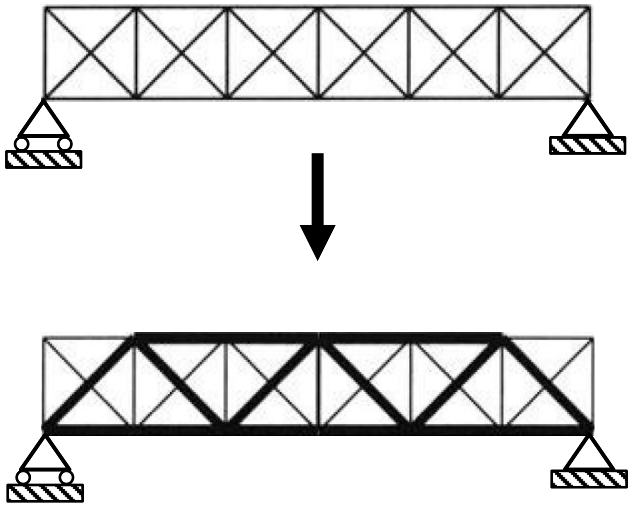


elise.de

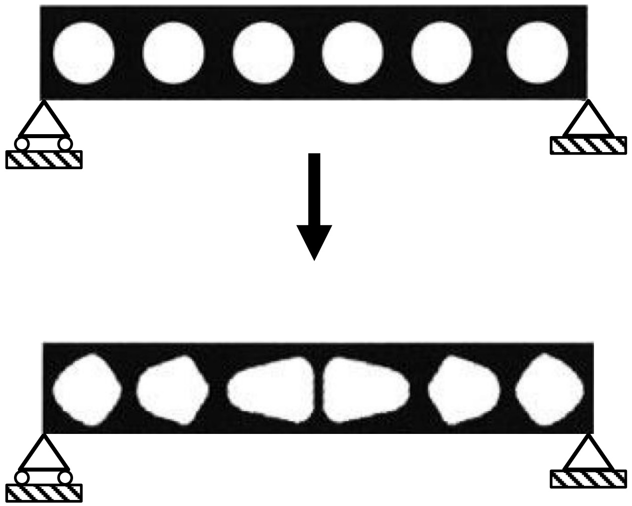
[5] Willkomm, J.; Jauer, L.; Ziegler, S. & Schleifenbaum, J.H. (2020): Development of individual medical implants with specific mechanical properties manufactured by Laser Powder Bed Fusion

Lightweight Design
Structural Optimization Methods

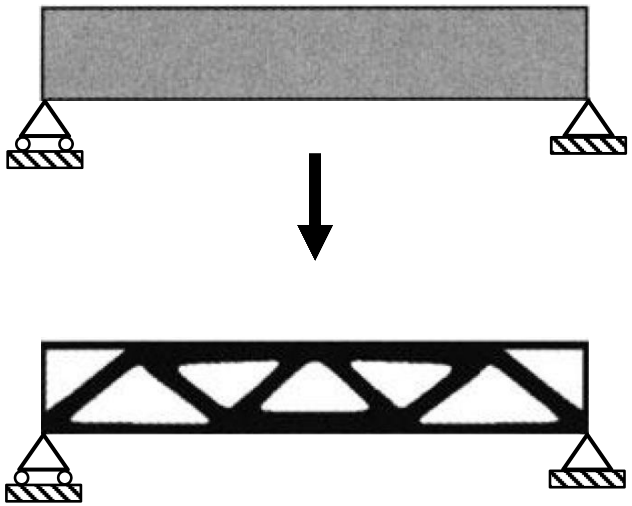
Size Optimization



Shape Optimization



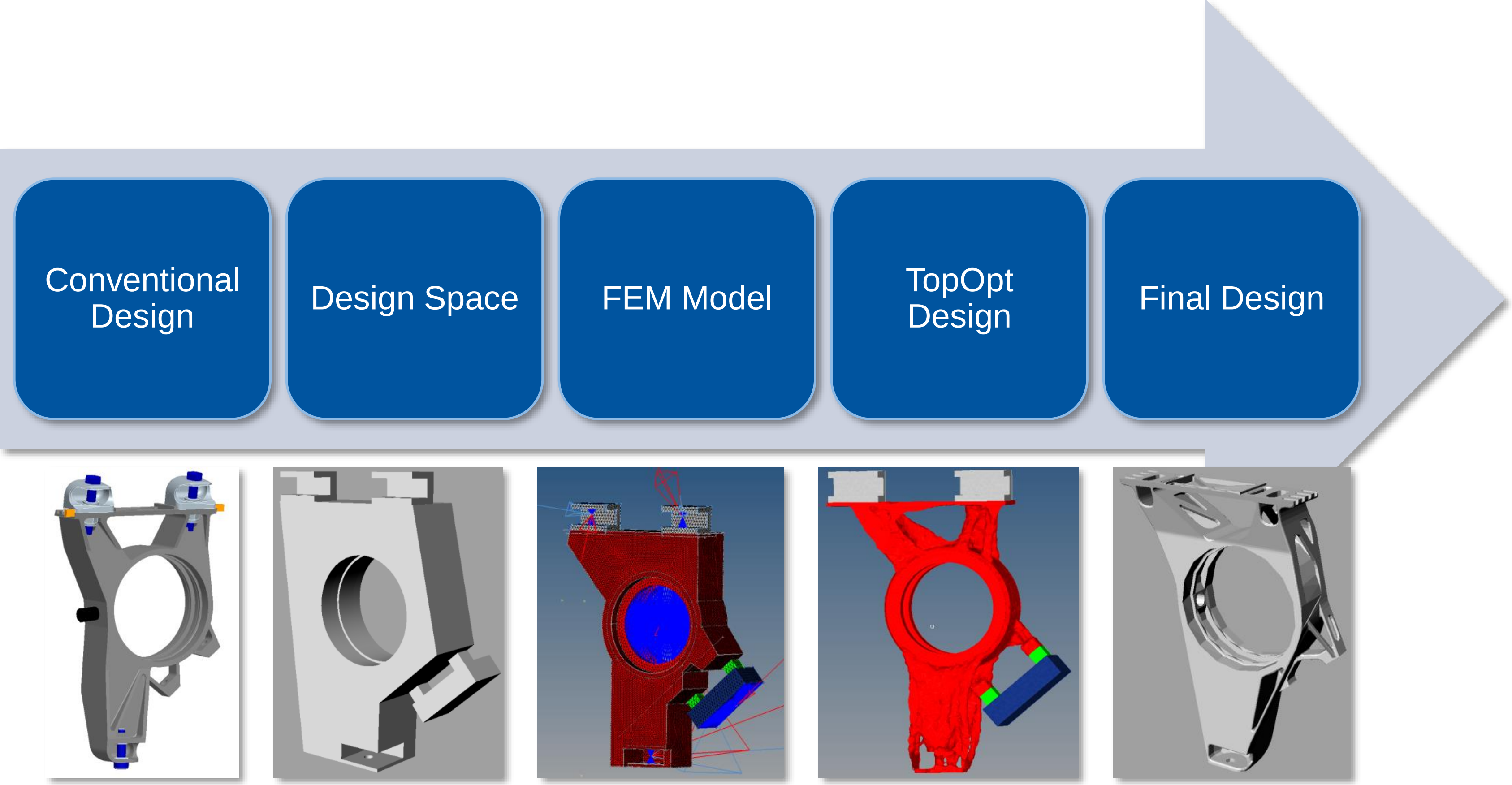
Topology Optimization



Bendsoe & Sigmund (2004): Topology Optimization

Lightweight Design
Topology Optimization

- Material and weight efficiency by finding the optimal material distribution within a part
  - Optimization criteria, e.g.
    - Maximizing stiffness
  - Objective, e.g.
    - Defined volume / mass reduction



Source: Fraunhofer ILT

Lightweight Design
Lattice Structures

Lightweight Structures

- Material reduction
- Increasing the strength to weight ratio

e.GO

Thermal Insulation

- Filigree lattice structures can restrict convection
- Gas can get trapped in lattice cells
- Low gas velocity

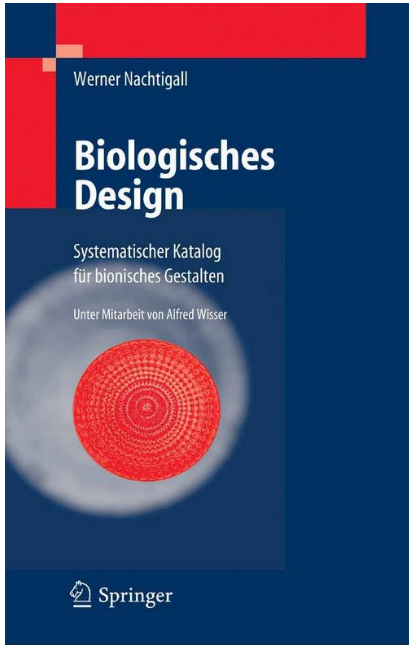
altairenlighten.com

Lightweight Design
Biomimetic Design Strategy

„Biomimetics combines the disciplines of biology and technology with the goal of solving technical problems through the abstraction, transfer, and application of knowledge gained from biological models.“ VDI 6220 Blatt 1

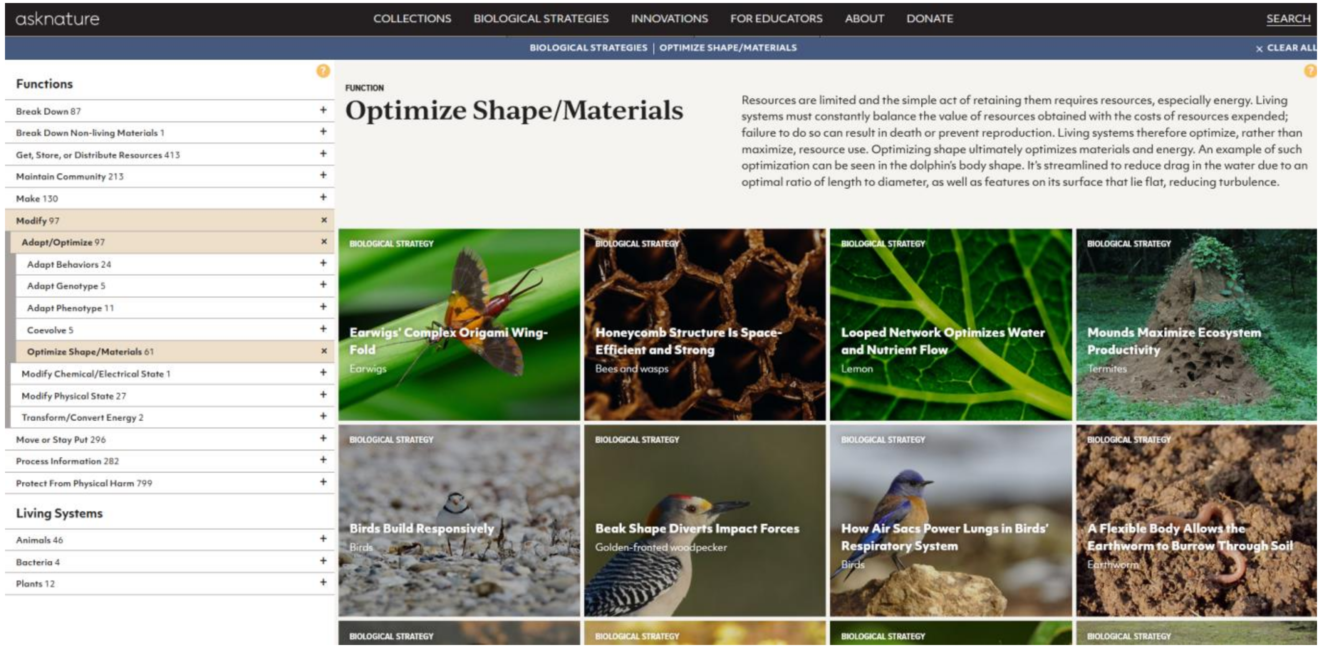
Technical Problem → Searching for biological models → Understanding the functional principle → Abstraction of the principle → Technical Application

Design Catalogue

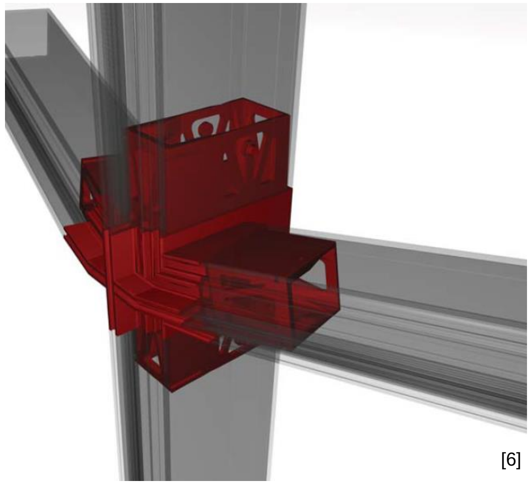


Online Databases e.g. asknature.org

asknature.org



Application of AM in the Construction Industry
Nematox II Façade Node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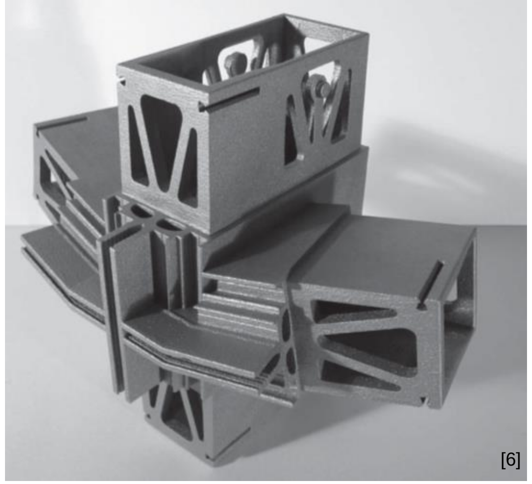

[6]


[4]

- Hybrid solution: combining parametrically planned, individualized parts with tested and verified systems
- Nodes had to fit the standard aluminum profile → assembly friendly
- All angles can be digitally adjusted to the desired geometry → realization of free-formed facades
  - Angular deformation of the façade is solved with the nodes, the connections are realized with 90° cuts
  - Reduction of cutting scraps, assembly time and inaccuracies

[4] Strauß, Holger (2013): AM Envelope. The potential of Additive Manufacturing for façade construction
[6] Strauß, Holger; Knaack, Ulrich (2015): Additive Manufacturing for Future Facades: The potential of 3D printed parts for the building envelope

Application of AM in the Construction Industry

HivE – N-AM_Li3


li3designers.com

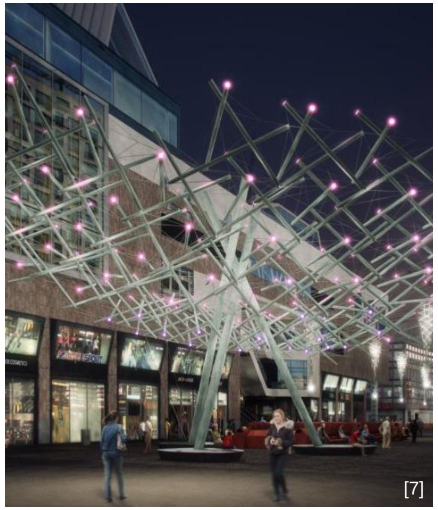
haute-innovation.com

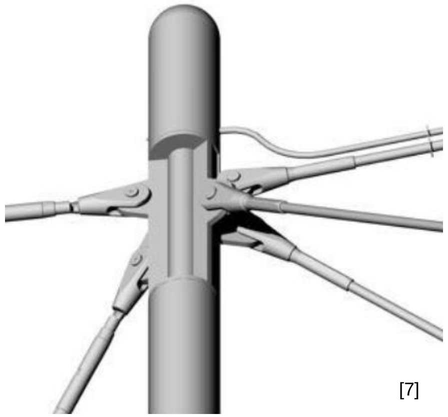
- Additively manufactured 3D façade nodes for aluminium Profile Systems
- Improvements for a greater design freedom of the façade
- Winner: ICONIC AWARDS 2022: Innovative Architecture

  Categories: Façade Design & Innovative Material
- 23m façade length
- 138 parametrically generated and topology optimized aluminium nodes
- Individually optimized for the respective loads
- First certified 3D printed façade node in Germany, approval in an individual case in May 2021

Application of AM in the Construction Industry

Example – Node of a Tensegrity Structure


[7]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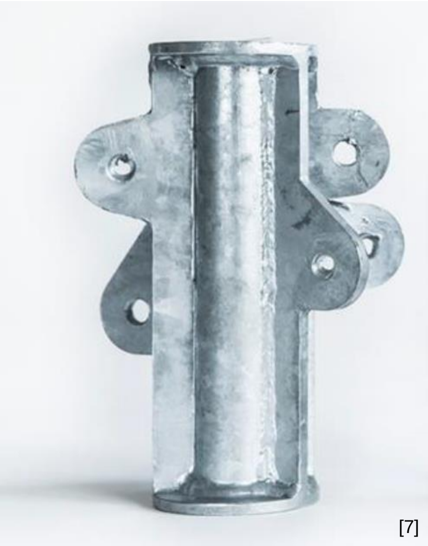
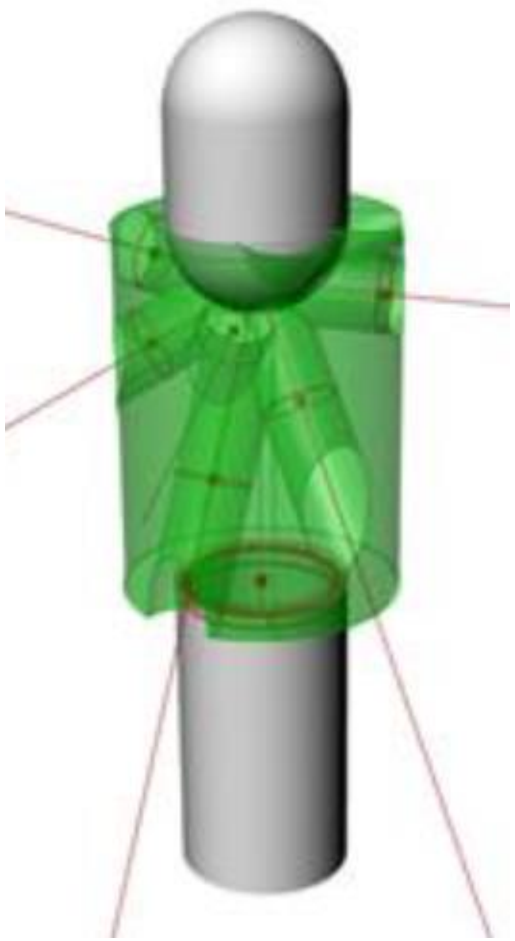

[7]


[7]

- Conventional Production: each node is made from 6-7 unique machined steel plates, welded on a central tube in varying directions
- All structural nodes have slightly different shapes: 1200 variations in angle and position of the attached cables
- Re-design of one exemplary node, exploring the opportunities of using the design freedom created by AM
- Topology optimization: minimizing total material weight, while satisfying max. von Mises Stress
- Optimization for production: self-supporting
- Economically not yet worthwhile compared to traditionally welded parts
- Material savings, limited storage and transport costs, simplified assembly

[7] Galjaard, Salomé; Hofman, Sander; Perry, Neil; Ren, Shibo (2015): Optimizing Structural Building Elements in Metal by using Additive Manufacturing

Application of AM in the Construction Industry
Example – Node of a Tensegrity Structure


[7]


[7]

- Function integration: provide connection to cables, strut and lighting fixture
- Greater design freedom than before → better result
- Design process (simplified):
  - Parametric modeling of the design space
  - Topology optimization
  - Design adjustments
- Weight reduction of the nodes leads to weight reduction of overall structure → further weight reduction of the nodes possible

[7] Galjaard, Salomé; Hofman, Sander; Perry, Neil; Ren, Shibo (2015): Optimizing Structural Building Elements in Metal by using Additive Manufacturing

Application of AM in the Construction Industry

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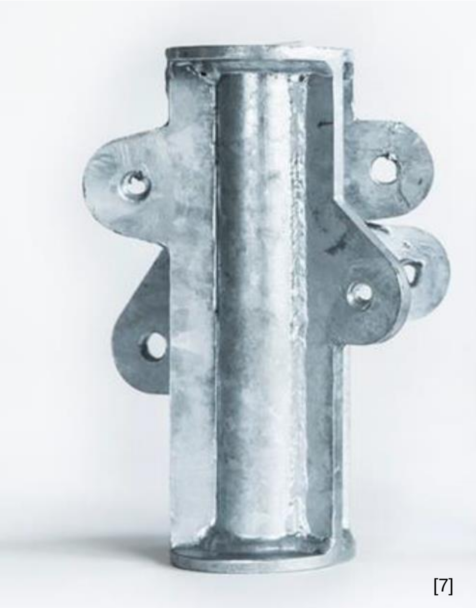

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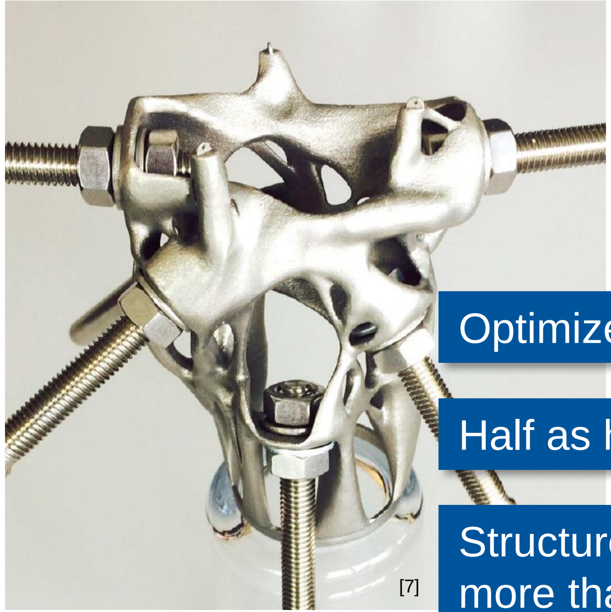

[7]

Optimized node is 75% lighter

Half as high as the original

Structure as a whole could be more than 40% lighter than before

[7] Galjaard, Salomé; Hofman, Sander; Perry, Neil; Ren, Shibo (2015): Optimizing Structural Building Elements in Metal by using Additive Manufacturing

Conclusion

Sustainability in the Construction Industry Using Additive Manufacturing

- Energy efficiency by means of reduction of thermal bridges

  → elaborate geometries, which have a reduced thermal conduction

- Material and resource efficiency

  → design optimization and lightweight engineering

- Promoting re-using of load bearing structures in the construction industry

  → increasing the rate of re-use through detachable connections

- Reduction of energy used for material preparation

  → using recycled material instead of newly mined material

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Your contact

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