# 3D printed steel bridge: from Additive to Augmented Manufacturing

Prof. dr. ir. Jouke Verlinden, Faculty of Design Sciences

MX3D

University of Antwerp

# Industry 4.0: .. Creative industry perspective

- Background
- Product Design 4.0 & Digital fabrication
- Wire and Arc Additive Manufacturing in the wild…
- Augmented Manufacturing

Takeaway:
#1: Work with artists as though leaders in design
#2: Think beyond Manufacturing & embrace Augmented technologies

# About the speaker

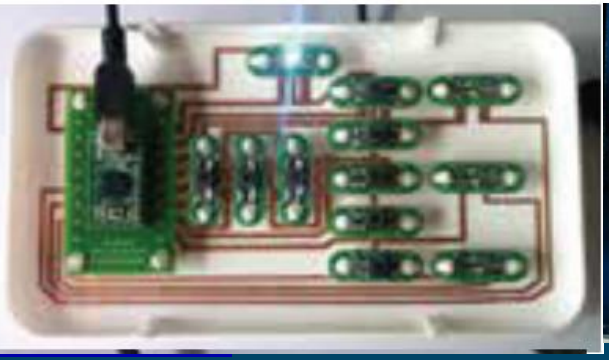
Professor in Human-centered Digital Fabrication

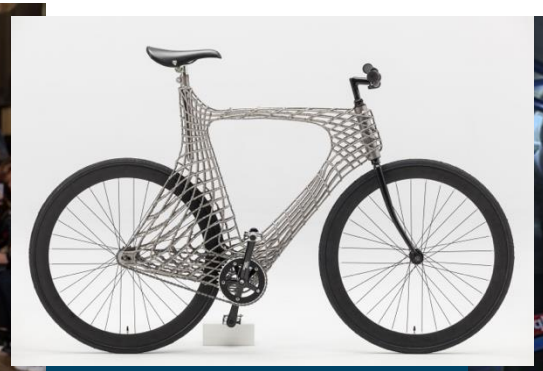
- Additive Manufacturing & Robotics
- Virtual & Augmented Reality

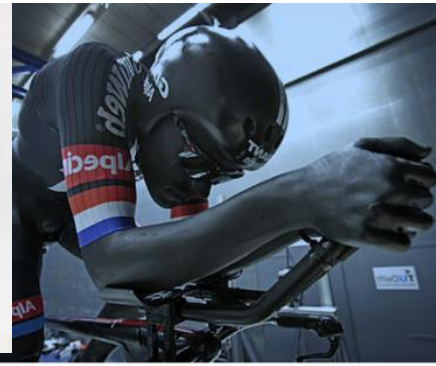
→Crossing boundary between design & engineering

→Connecting to thought leaders

→Make moonshots/demonstrators/provotypes







# Manufacturing trends

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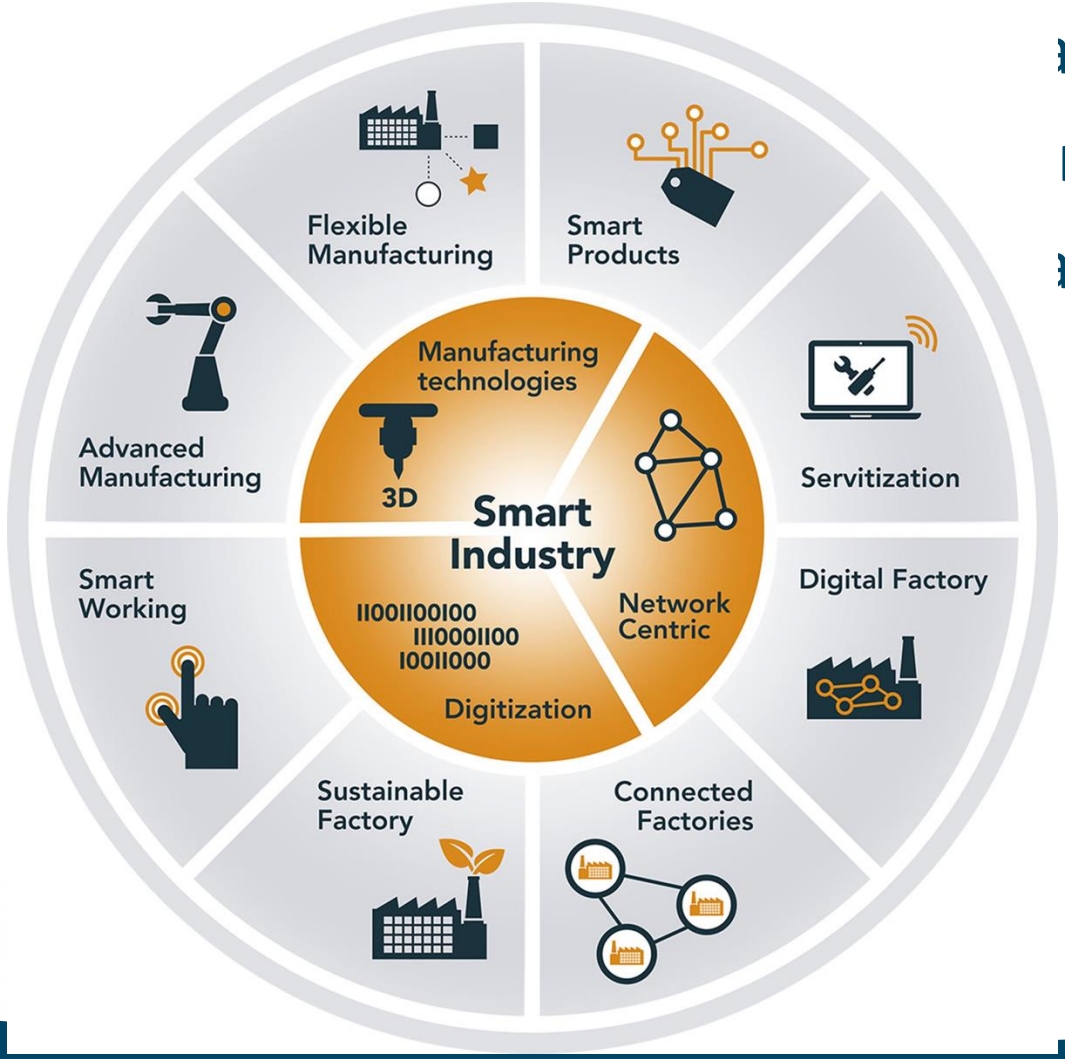
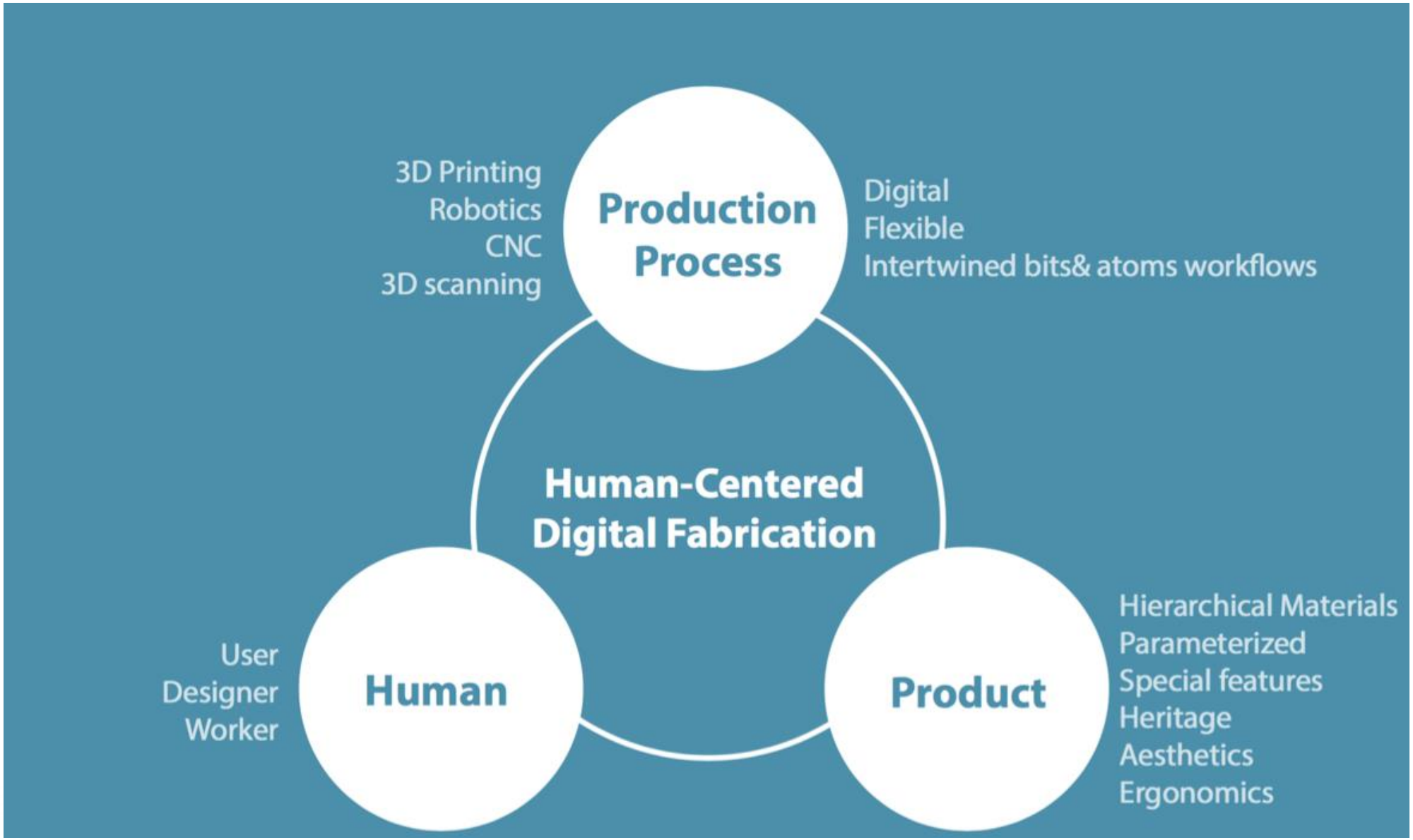
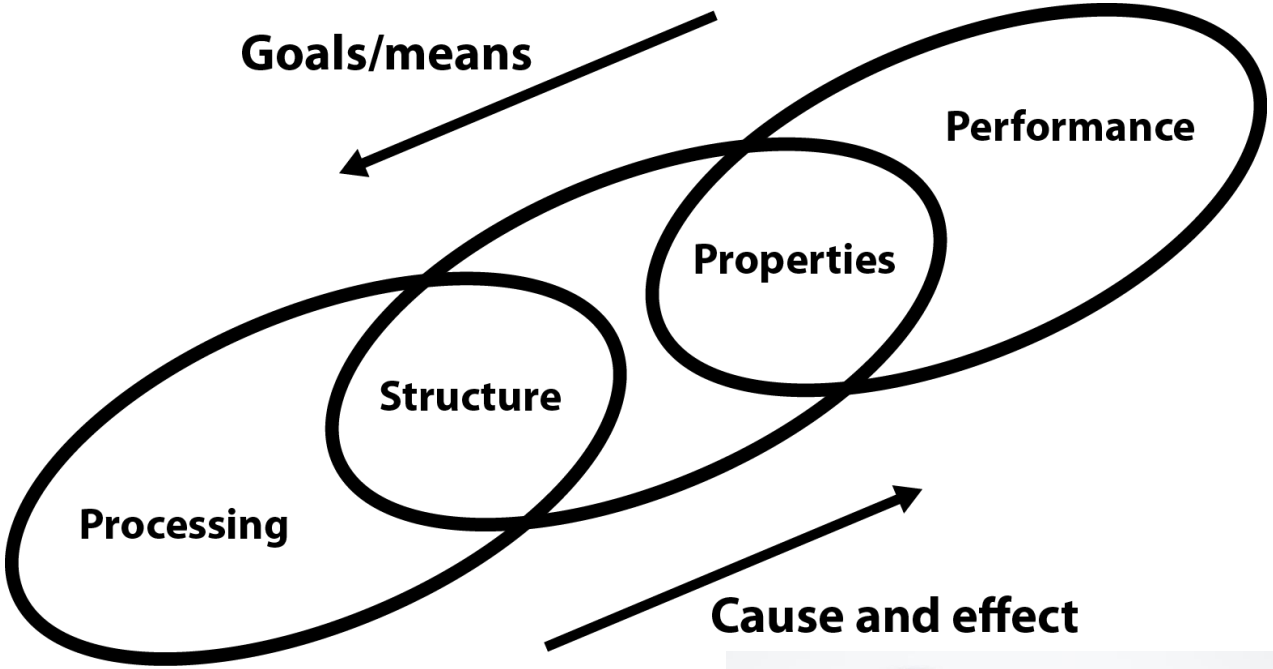


# Product Design 4.0

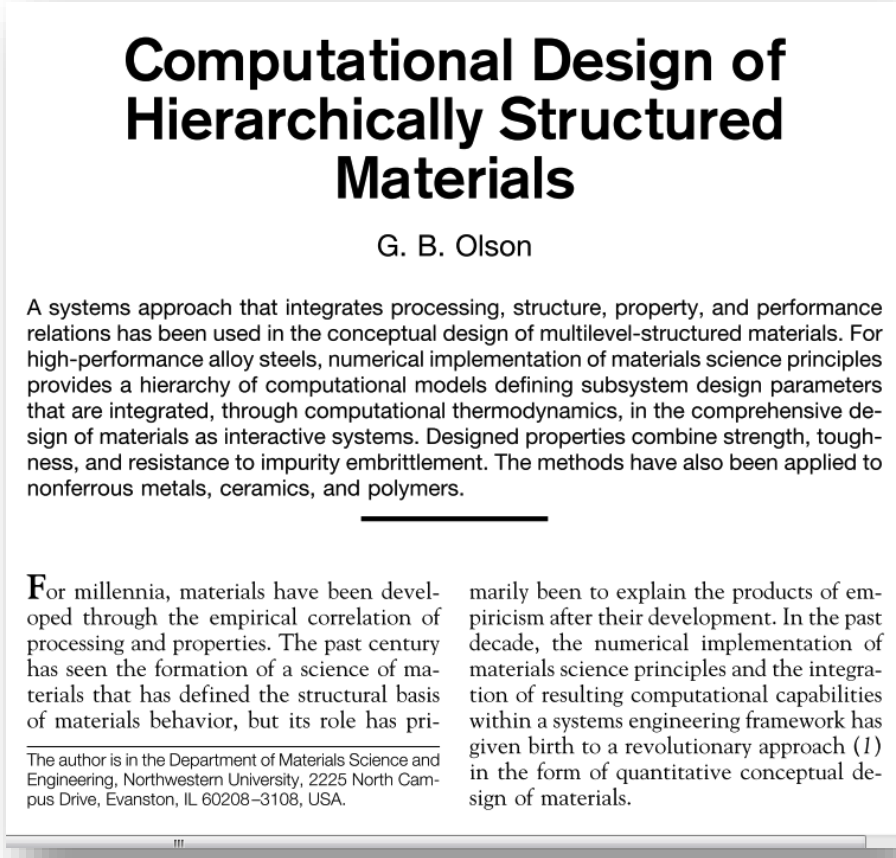


# Hierarchical materials: 3-Link Chain Model



Metamaterials, 4D printing, Origami

Topological optimisation



## Computational Design of Hierarchically Structured Materials

G. B. Olson

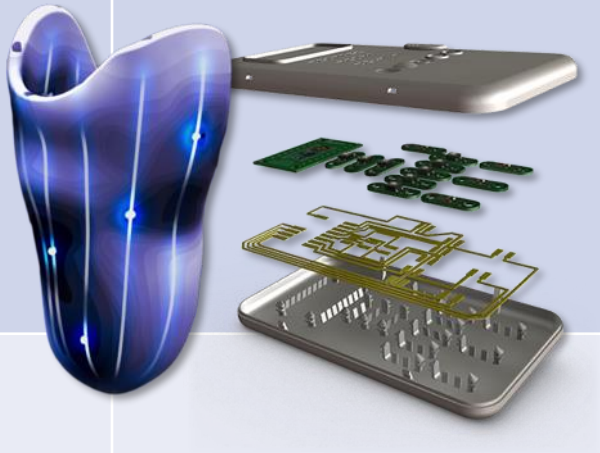
A systems approach that integrates processing, structure, property, and performance relations has been used in the conceptual design of multilevel-structured materials. For high-performance alloy steels, numerical implementation of materials science principles provides a hierarchy of computational models defining subsystem design parameters that are integrated, through computational thermodynamics, in the comprehensive design of materials as interactive systems. Designed properties combine strength, toughness, and resistance to impurity embrittlement. The methods have also been applied to nonferrous metals, ceramics, and polymers.

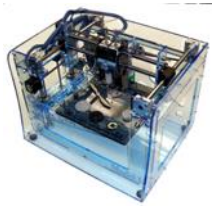
For millennia, materials have been developed through the empirical correlation of processing and properties. The past century has seen the formation of a science of materials that has defined the structural basis of materials behavior, but its role has primarily been to explain the products of empiricism after their development. In the past decade, the numerical implementation of materials science principles and the integration of resulting computational capabilities within a systems engineering framework has given birth to a revolutionary approach (*1*) in the form of quantitative conceptual design of materials.

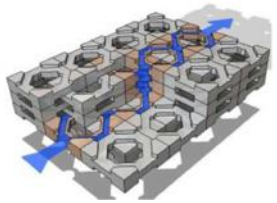
The author is in the Department of Materials Science and Engineering, Northwestern University, 2225 North Campus Drive, Evanston, IL 60208–3108, USA.

*Olson (1997) Science 277, 1237*

# Progress in Digital Fabrication…

| Past (-5 years) | Present | Future (+5 years) |
|---|---|---|
| “Controlling form&shape”<br><br>Freeform surfaces<br>Anisotropy<br>Stair casing<br>Brittle | “Controlling internal composition”<br><br>Parameterized solids<br>Multi-material/ functionally graded<br>Three-link chain model |  |
| High-tech<br><br>Rapid Prototyping<br>Rapid tooling | Fablab & hi-tech<br><br>Additive manufacturing/ Products on demand | |
| Fab@home | Food<br>Reconfigurable voxels | |





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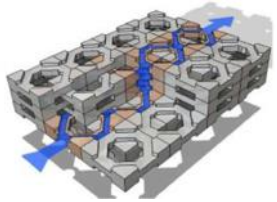
| High-tech<br><br>Rapid Prototyping<br>Rapid tooling | Fablab & hi-tech<br><br>Additive manufacturing/<br>Products on demand | |
| Fab@home | Reconfigurable voxels<br>Food | |



# Progress in Digital Fabrication…

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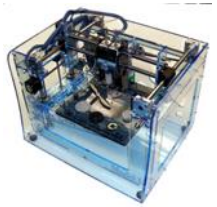
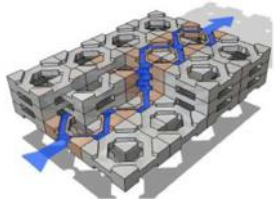
| [redacted] | [redacted] | “Controlling functional behavior”<br><br>4D printing/soft robotics<br>High-speed printing<br>Swarm printing &<br>Mega-scale printing<br>Home? Hospital? Library? |
| [redacted] | [redacted] | |
| [redacted] | [redacted] | |

Opening sequence “WestWorld”(HBO)





# Design for 3D printed Metal

## MX3D / 3D Building FieldLab

http://mx3d.com/field-lab-2

# Design for 3D printed Metal

ArcelorMittal

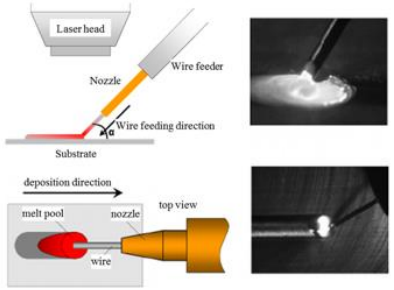
STV WELDINGSUPPLIES.NL

JUNGHEINRICH

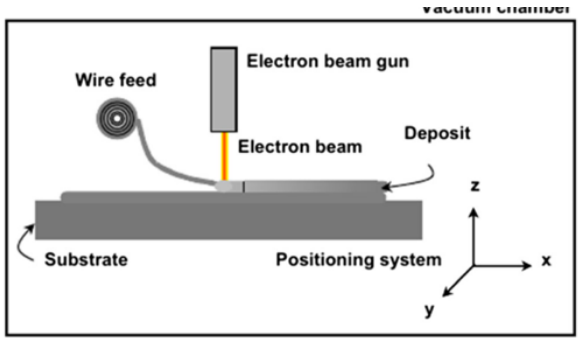
TU Delft Delft University of Technology

http://mx3d.com/field-lab-2

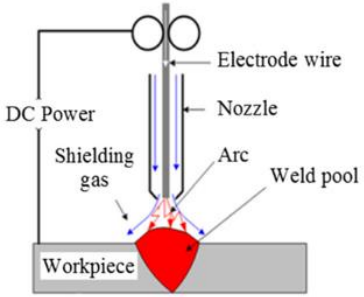
# Wire & Arc Additive Manufacturing




Wire Laser AM



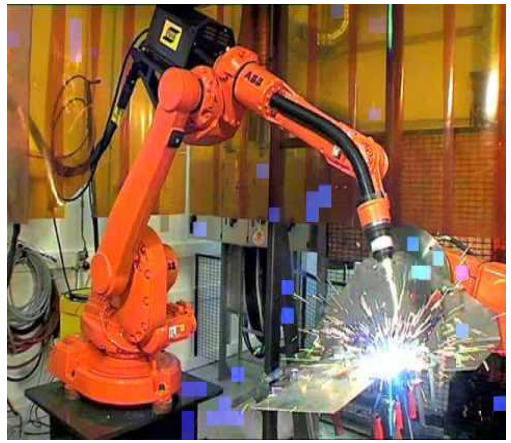

Electron Beam Forming




Wire Arc AM

**Motion/control**

Compound

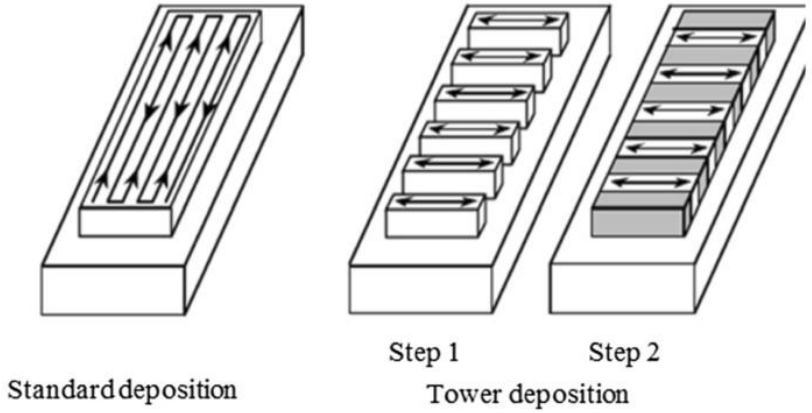


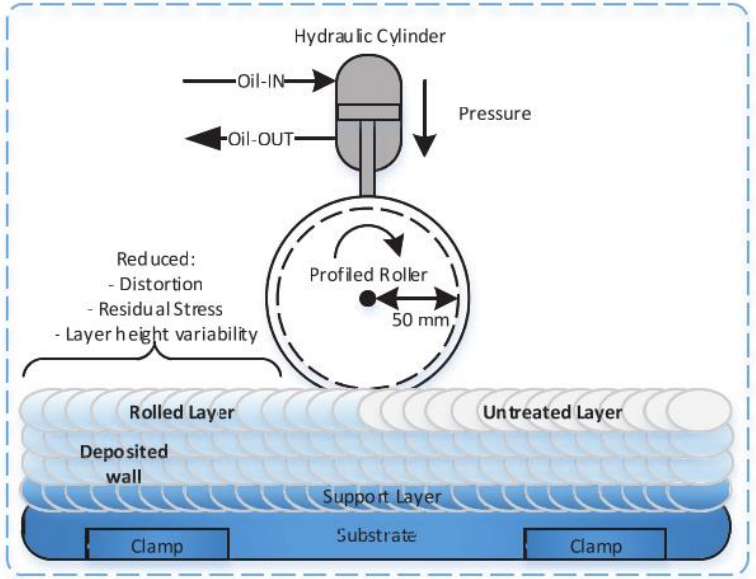
Articulated arm

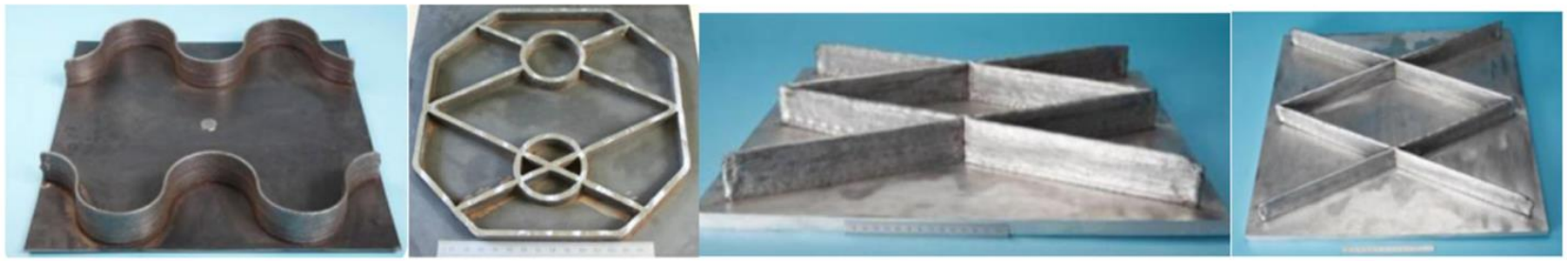
orthogonal

Ding, D., Pan, Z., Cuiuri, D., & Li, H. (2015). Wire-feed additive manufacturing of metal components: technologies, developments and future interests. *International Journal of Advanced Manufacturing Technology*, *81*(1-4), 465–481. http://doi.org/10.1007/s00170-015-7077-3Wi

# Printing strategies

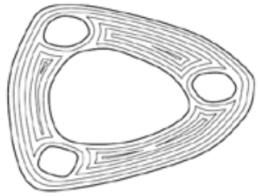


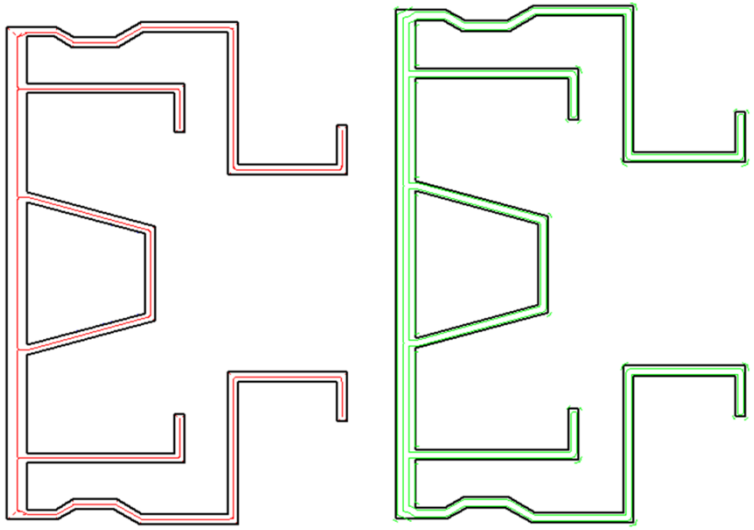



# Slicing strategies (planar)

**Table 1** A brief summary of AM tool-path generation methods.

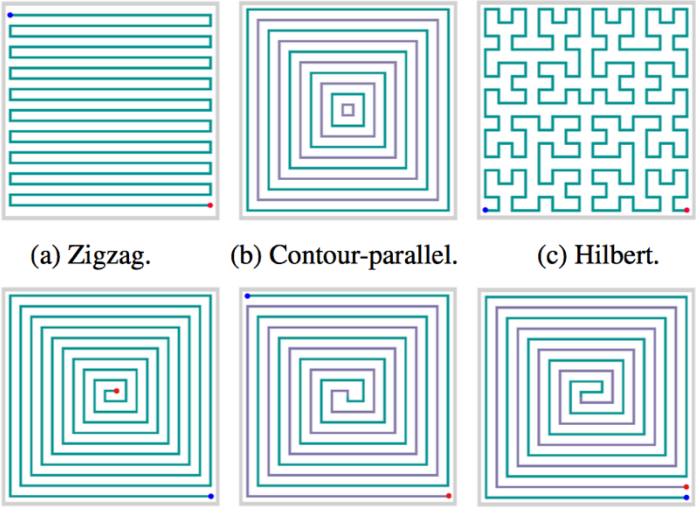
| References | Tool-path pattern | Examples |
|---|---|---|
| [13] | Raster | |
| [14, 15] | Zigzag | |
| [16-18] | Contour |  |
| [19, 20] | Spiral | |
| [21-24] | Continuous | |
| [25, 26] | Hybrid | |



(a) (b)

Fig. 15 Geometry 4, thin-walled complex structure. (a) Geometry is represented by black lines, MAT represented by dotted red lines, and red solid lines stand for branches. (b) Generated trimmed path.

(Median-axis Transform)



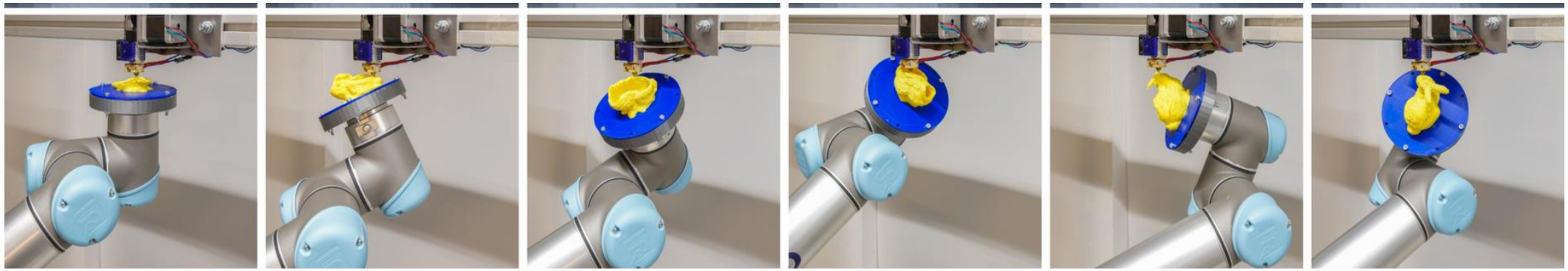
(a) Zigzag. (b) Contour-parallel. (c) Hilbert.

(d) Spiral. (e) Fermat spiral 1. (f) Fermat spiral 2.

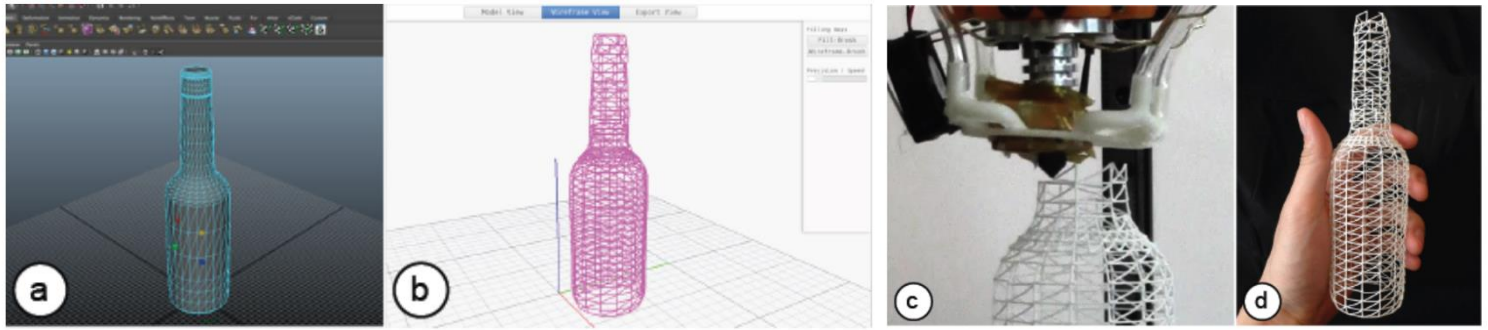
Haisen Zhao, Fanglin Gu, Qi-Xing Huang, Jorge Garcia, Yong Chen, Changhe Tu, Bedrich Benes, Hao Zhang, Daniel Cohen-Or, and Baoquan Chen. 2016. Connected fermat spirals for layered fabrication. ACM Trans. Graph. 35, 4,.

Ding, D., Pan, Z., Cuiuri, D., & Li, H. (2015). A practical path planning methodology for wire and arc additive manufacturing of thin-walled structures. *Robotics and Computer Integrated Manufacturing, 34 8-19.*

# Slicing strategies (non planar)

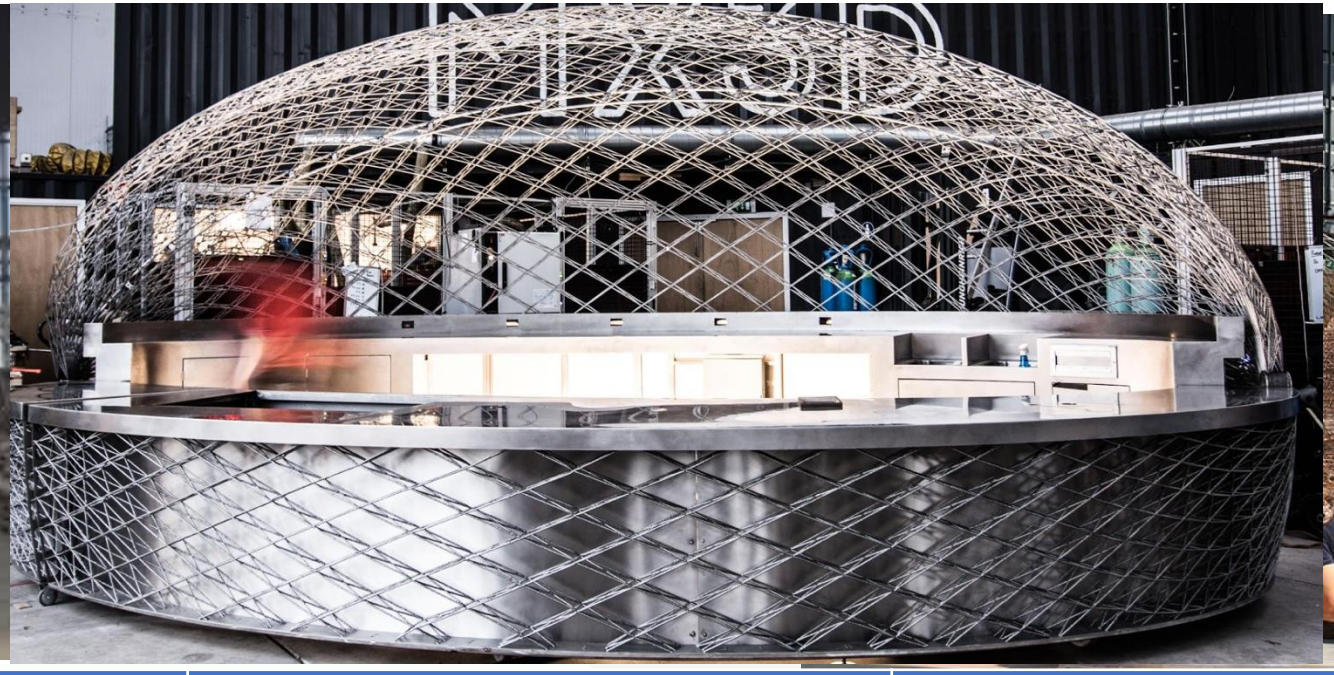


Chengkai Dai, Charlie C. L. Wang, Chenming Wu, Sylvain Lefebvre, Guoxin Fang, and Yong-Jin Liu. 2018. Support-free volume printing by multi-axis motion. ACM Trans. Graph. 37, 4,




Stefanie Mueller, Sangha Im, Serafima Gurevich, Alexander Teibrich, Lisa Pfisterer, François Guimbretière, and Patrick Baudisch. 2014. WirePrint: 3D printed previews for fast prototyping. In Proceedings of the 27th annual ACM symposium on User interface software and technology (UIST '14).

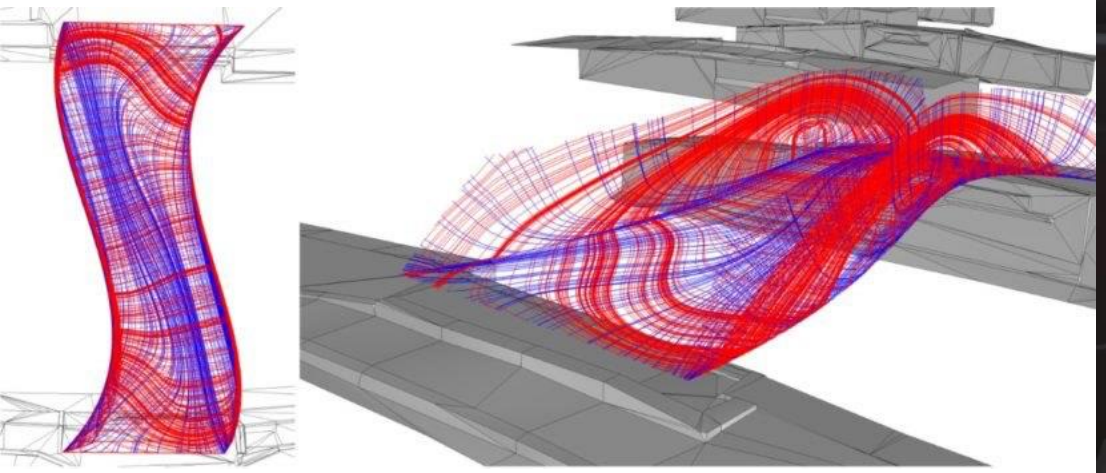
# MX3D



| People | Planet | Profit |
|---|---|---|
| • Better designs (aesthetics/ergonomics/ dynamics)<br>• Infrastructural solutions for smarter cities<br>• Localised manufacturing | Resources, logistics<br>Environmental impact<br>Value chain | Time to market<br>Business models (on demand, customized heritage)<br>Novelty |

http://mx3d.com/field-lab-2

# 3D Printed Bridge



Stress lines analysis

# Comparisons…

| | WAAM | Selective Laser Melting |
|---|---|---|
| Captial cost | € 75,000 | € 500,000-1,500,000 |
| Raw material cost | € 2/kg | € 80/kg |
| Deposit rate | 1-7 kg/hr | 0.1-0.2 kg/hr |
| Accuracy | 0.5 mm | 0.005 mm |
| Build volume | Virtually unlimited | 800 x 400 x 500 mm |

Life Cycle analysis

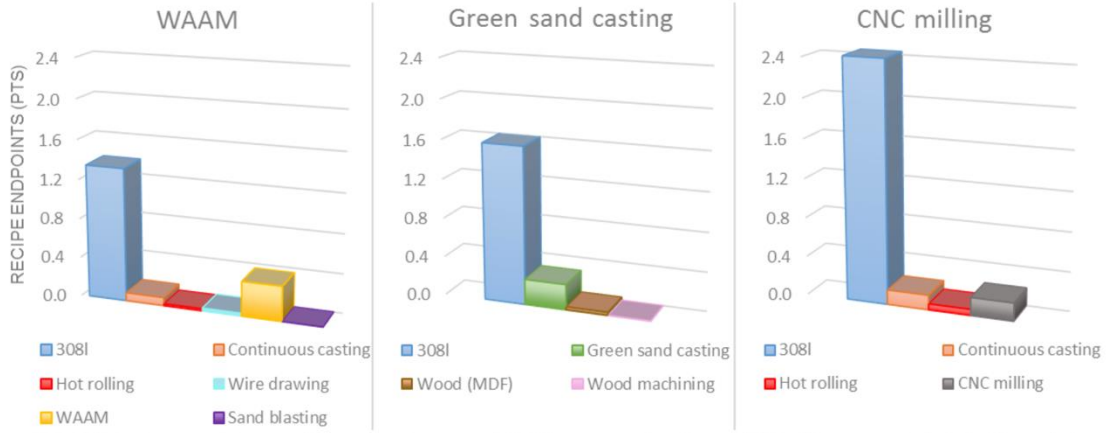
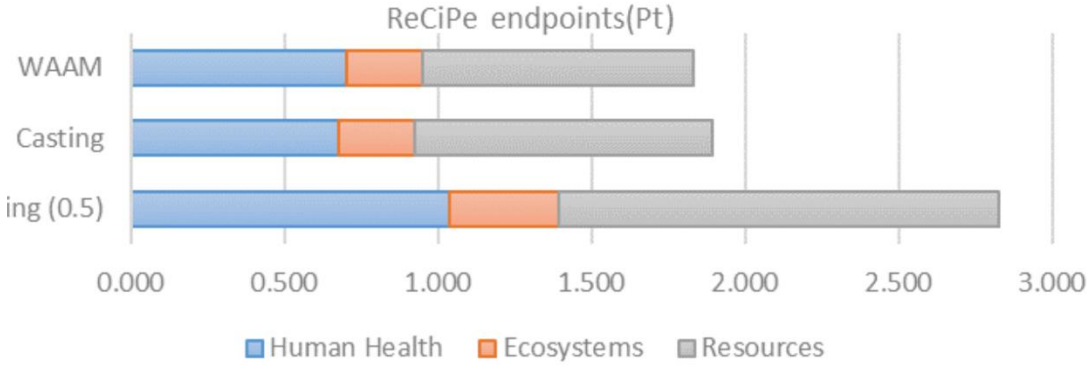



**FIGURE 4.** Environmental impacts of the processing steps of WAAM, green sand casting, and CNC milling respectively, in ReCiPe endpoints (Pts), per kg of manufactured 308l product.



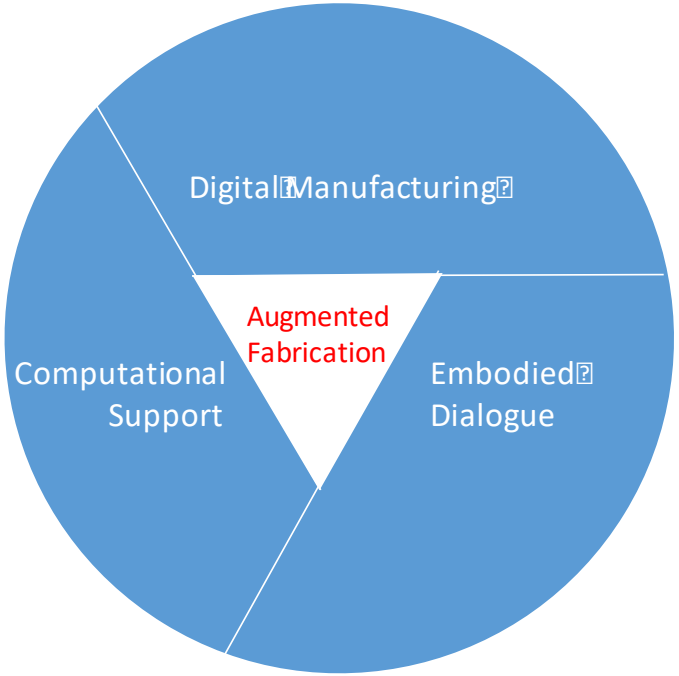

Bekker, A. C., & Verlinden, J. C. (2018). Life cycle assessment of wire+ arc additive manufacturing compared to green sand casting and CNC milling in stainless steel. Journal of Cleaner Production, 177, 438-447.

# Augmented Fabrication

**Design and prototyping of custom digital fabrication systems that combine user skills/intuition with computational power -- Augmented Reality**

# Augmented Fabrication

## Designing with/for cyber-physical manufacturing



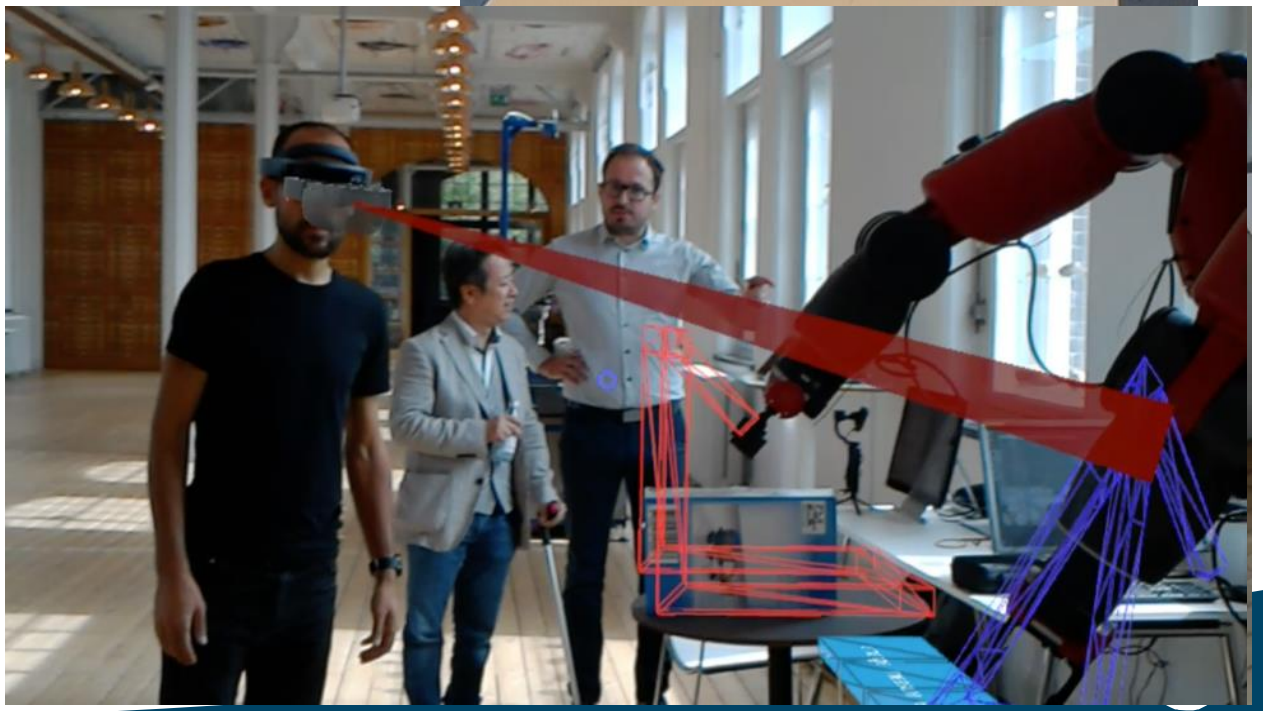

**Computational support**

**Embodied dialogue**

**Digital Fabrication**

| | | | | |
|---|---|---|---|---|
| | Prototyping | Deployment | Manufacturing | Product (Digital twin) |
| | Conceptualization | Production Planning | Production | Use/Maintenance |

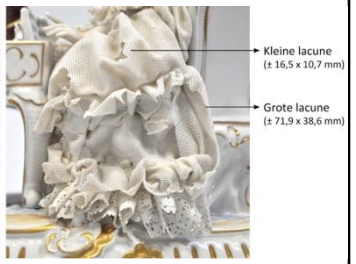
# Augmented Fabrication: Hololens in factory of the future



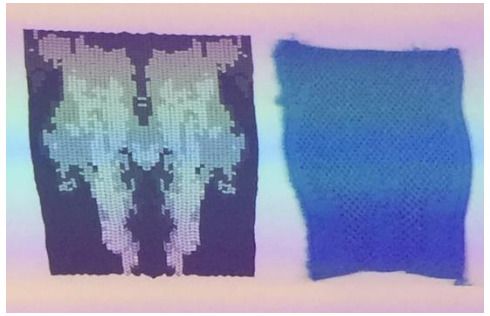
# Augmented Fabrication @ Antwerp 2020

## Augmented Reality for design/manufacturing

## Cultural Heritage




## Digital fabrics and ultra-personalized fashion



## Gel printing

# Conclusions

## Don’t automate: augment!

jouke.verlinden@uantwerpen.be

MX3D

University of Antwerp