

GE 10) INDUSTRY 4.0 & ADDITIVE MANUFACTURING

Report Presentation

AKEDDAR Hamza
LUNDBY Signe
MAITROT Adrien
MITRIC Marko
STAWARZ Mathieu

Summary

- 01** Industry 4.0 and AM overview
- 02** Lighthouses Leading AM Adoption
- 03** AI's impact on AM
- 04** Digital twins for AM
- 05** AM and Smart manufacturing
- 06** AM for a sustainable future
- 07** Conclusion

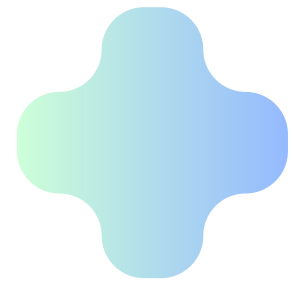


01

Industry 4.0 and AM overview

Introduction to the new digital revolution





The New Revolution : Advanced Digital technologies in **Industry 4.0**



Rapid development



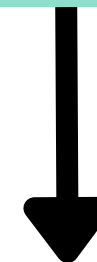
**4th Industrial
Revolution (4IR)**

Cyber-physical technologies

Blur the line between the physical,
digital, and biological worlds



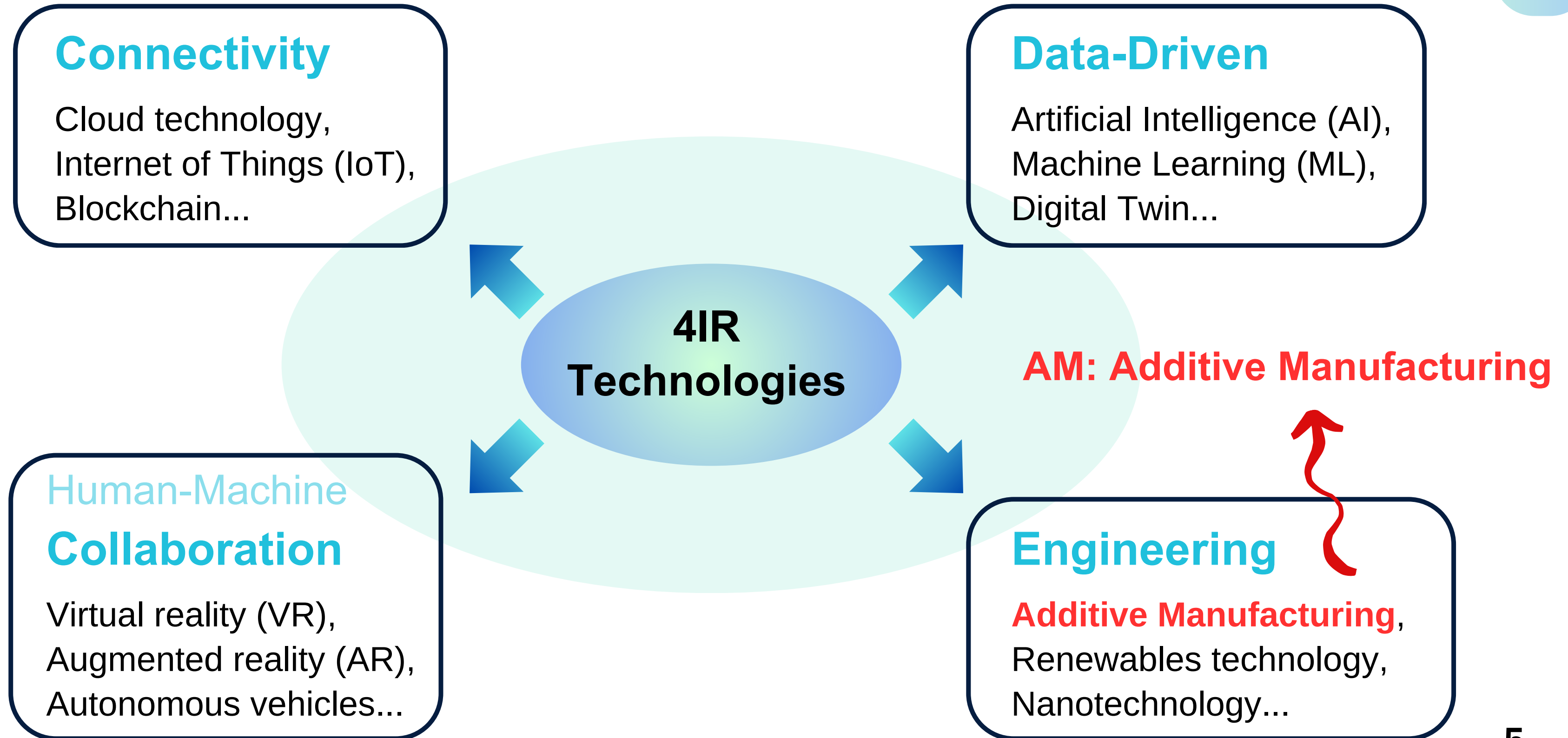
4IR technologies

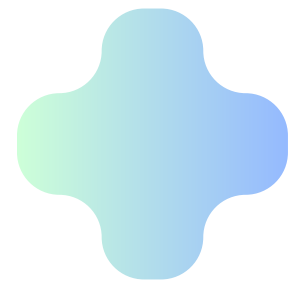


Change

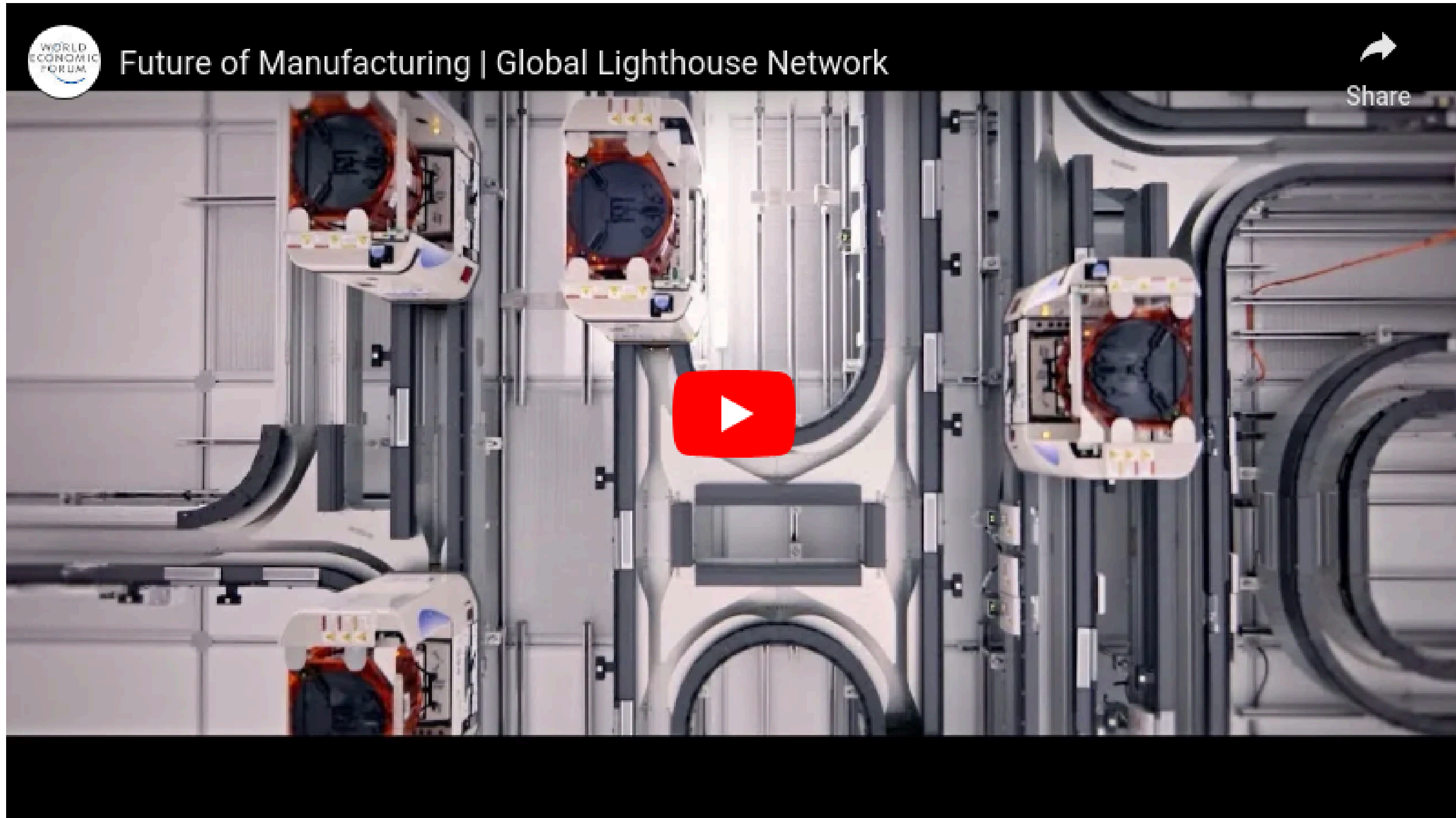
Manufacturing Industry

Industry 4.0 and Additive Manufacturing (AM)





WEF - Future of Manufacturing

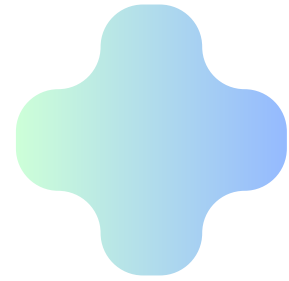


02

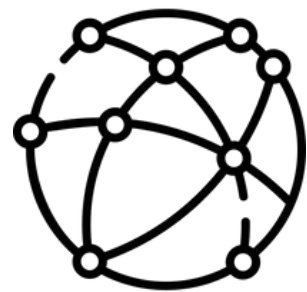
Lighthouses Leading AM Adoption

Mathieu Stawarz - 312865



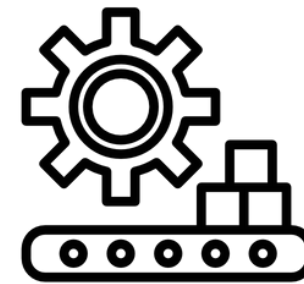


The Global Lighthouse Network (GLN)



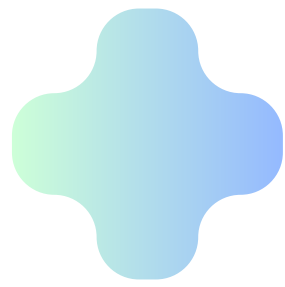
The Network

- **Hub** of 172 Lighthouses
- **12th wave** of Lighthouses
- **Boost** 4IR adoption
- **Strengthen** manufacturers
- **Mitigate** supply chain disruptions



Lighthouses sites (factories)

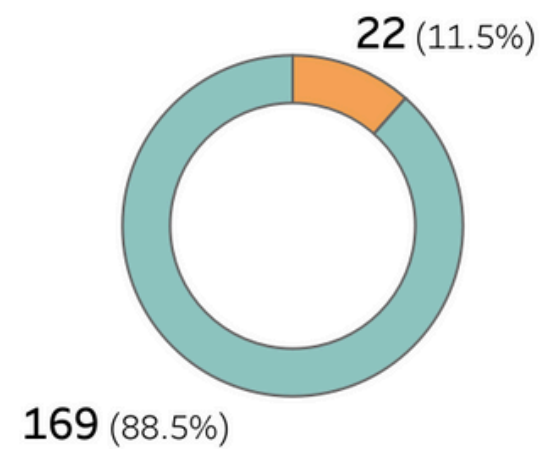
- **Recognition:** selected & identified
- **Success stories** : best 4IR tech adopters
- **Benchmarks:** inspire others as leaders
- **2 Distinctions:**
 (additional)
 - End to end (E2E)**
 - Sustainability**



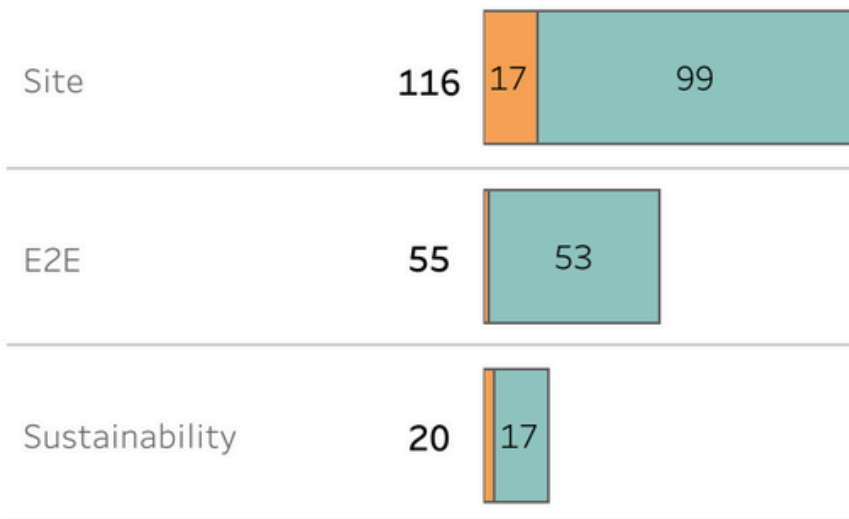
The Global Lighthouse Network (GLN)

W12 or Prior Waves *(Click to Filter)*

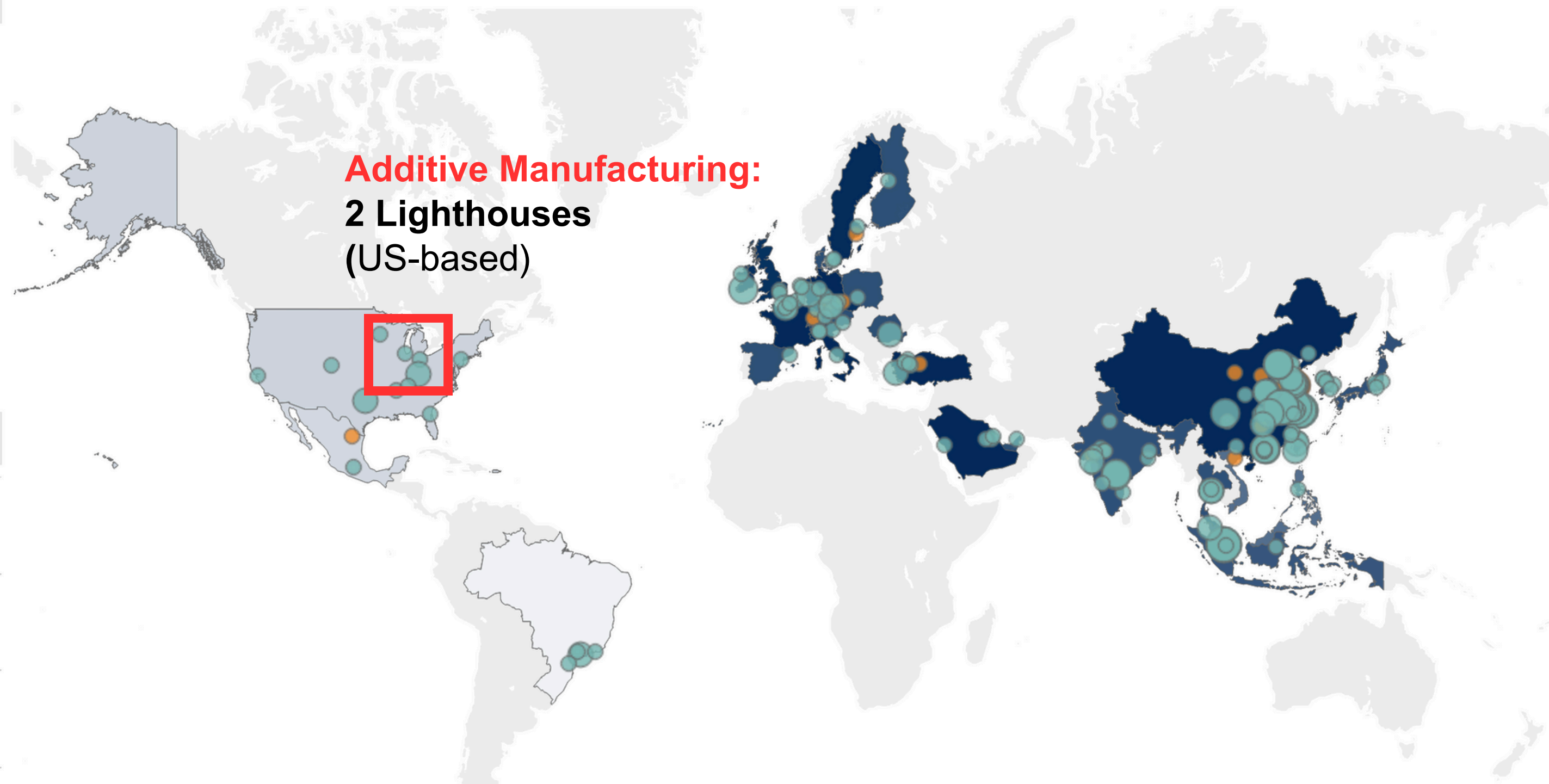
W12 Existing



Lighthouse Type *(Click to Filter)*



Hover over visual elements in the map to display more information & Click to display list by Country/Economy



Source: <https://initiatives.weforum.org/global-lighthouse-network/lighthouses>

Fast Radius AM Lighthouse:



HQ: US, near Chicago

- **Founded in 2014:** Pioneered additive manufacturing as a supply chain solution.
- **Partnered with UPS:** Established microfactories for 3D printing & logistics.

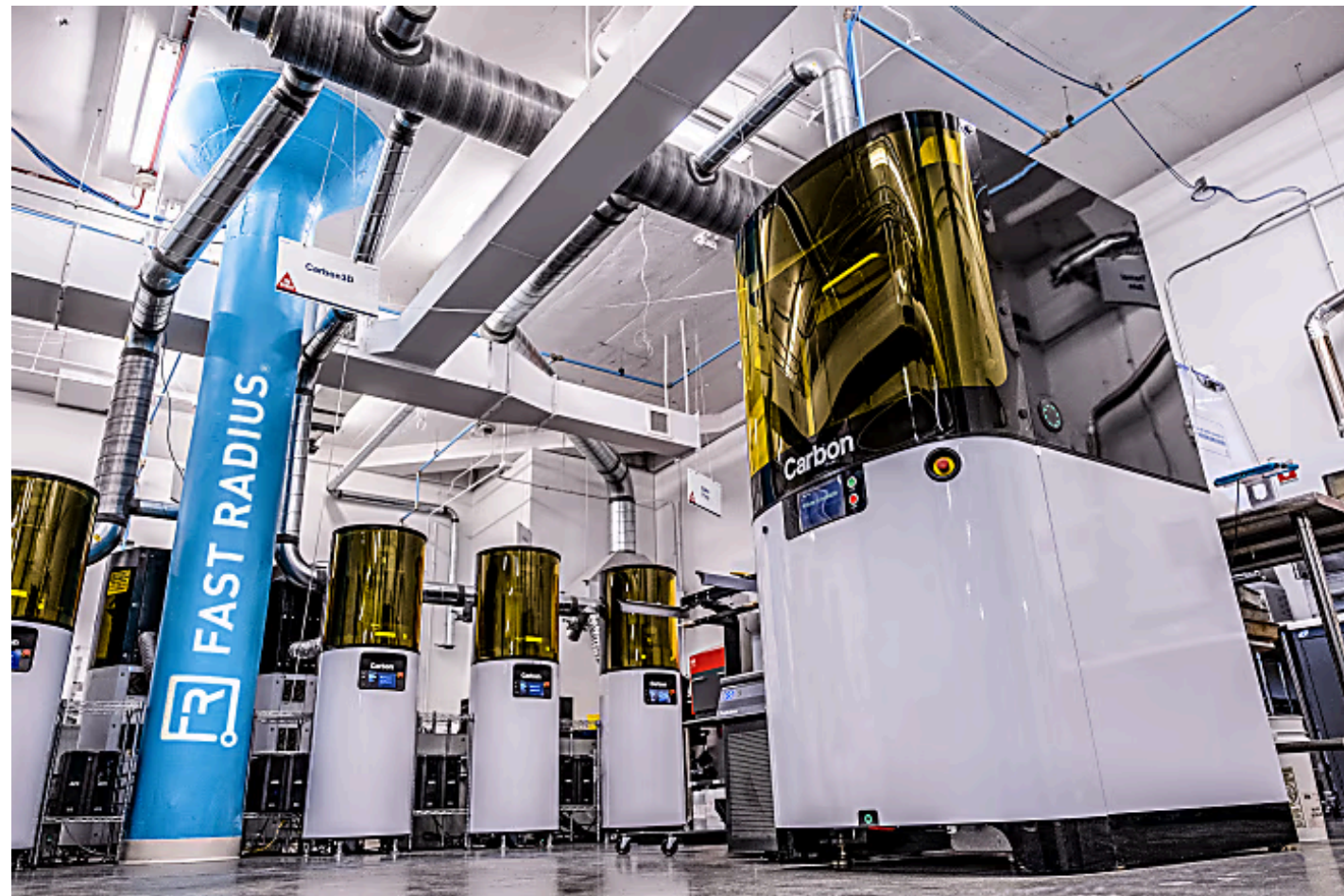


Image Source: <https://www.wsj.com/articles/fast-radius-files-for-bankruptcy-nine-months-after-spac-deal-11667940262>

- **Named Lighthouse Factory:** AM lighthouse for the 1st wave (2018).
- **Bankruptcy in 2022:** Lack of profitability, acquisition by Sybridge Tech
- **Largest Carbon DLS Install Base:** Leader in DLP 3D printing systems.
- **Served 2000+ customers:** Delivered 3D-printed parts to key industries.

ProtoLabs AM Lighthouse:

HQ: Maple Plain, Minnesota, U.S



- **Founded in 1999:**
Specialized in rapid custom plastic injection molding.
- **Entered 3D Printing (2014):**
Acquired FineLine Prototyping to enhance 3D printing capabilities.
- **Lighthouse Leader (2021):**
Recognized in WEF's GLN in the 7th wave
- **Protolabs Network Launch (2021):**
Acquired and rebranded Hubs, creating a global manufacturing platform.

- **Online 3D Printing Service:**

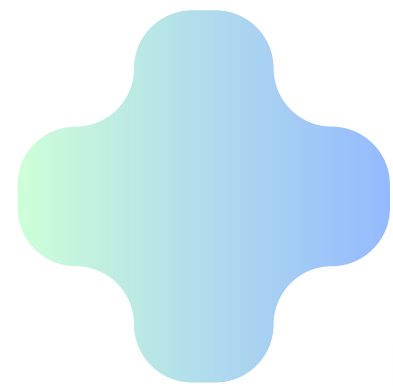
Offers six advanced technologies for producing plastic, metal, and elastomeric parts.

- **Global Presence:**

+2000 employees that operates facilities in the U.S., England, Germany, and Japan.



Image Source: <https://www.protolabs.com/services/3d-printing/direct-metal-laser-sintering/production-capabilities/>



Protolabs Network: 4IR Technology



From prototype parts to production runs

Prototyping

Production

- Instant quoting with free design analysis
- 100+ combinations of materials & surface finishes
- Quality prototypes and end-use parts in as fast as 1 day

Get an instant quote

 All uploads are secure and confidential

- **Global Partner Network:**

Matches orders to the best supplier among 250+ partners.

- **Instant Quotes with ML:**

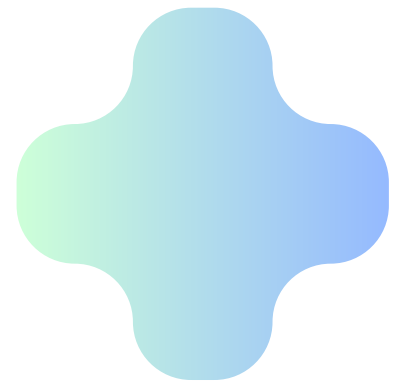
Upload CAD files for real-time costs, lead times, and specs.

- **Design Optimization:**

Refine designs using DFM tools and get tips to reduce costs and lead times.

- **Accessible to All:**

Open to both businesses and individuals, team collaboration tools.



Protolabs Network: 4IR technology For **Additive Manufacturing**



- **Global AM Network:**

+90 factories to meet the demand for 3D printed parts.

- **Skilled AM Network:**

Specialized 3D printing shops using FDM, SLA, SLS, and MJF technologies.



Online 3D printing service

The easiest way to source high-quality 3D printed prototypes and production parts. Order from our network of highly experienced 3D printing shops. ISO 9001, ISO 13485 and AS9100 certified.

[Get an instant 3D printing quote](#)

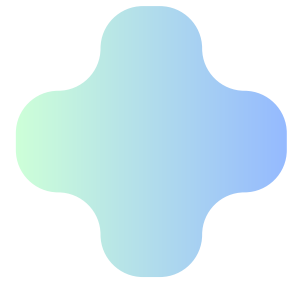
 All uploads are secure and confidential

- **On-Demand Production:**

Fast, customized parts without waiting for quotes.

- **Industrial Scale Printing:**

High-volume production and tooling, reducing costs.



Protolabs Network: 4IR technology For Additive Manufacturing



FDM

Fast & affordable
prototyping

- Dimensional accuracy of $\pm 0.5\%$ with a lower limit: ± 0.5 mm
- Lead times from 1 business day

[See our FDM services](#)

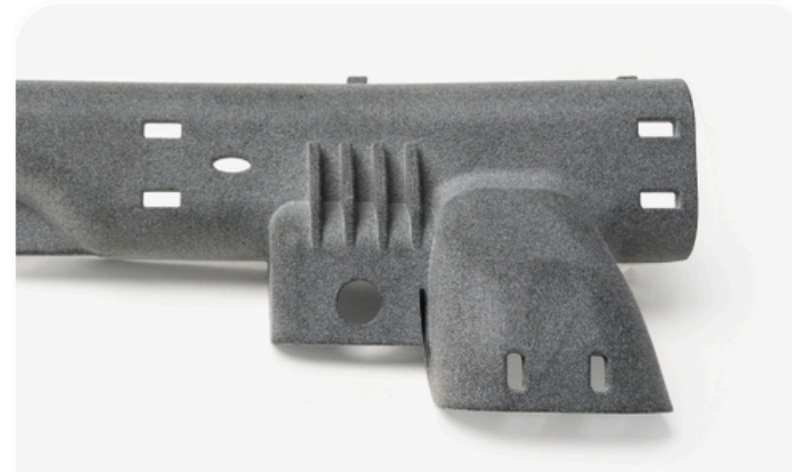


SLS

Functional prototyping &
low-run production

- Dimensional accuracy of $\pm 0.3\%$ with a lower limit of ± 0.3 mm ($\pm 0.012''$)
- Lead times from 3 business days

[See our SLS printing services](#)



MJF

Functional prototyping &
low-run production

- Dimensional accuracy of $\pm 0.3\%$ with a lower limit of ± 0.3 mm ($\pm 0.012''$)
- Lead times from 3 business days

[See our MJF services](#)



SLA

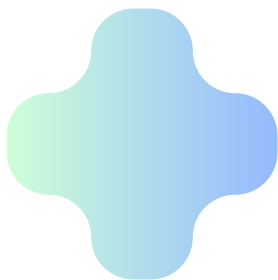
Visual prototyping

- Dimensional accuracy of $\pm 0.3\%$ with a lower limit of ± 0.3 mm ($\pm 0.012''$)
- Lead times from 2 business days

[See our SLA services](#)

X-Y Accuracy: 3-6 times less !

Protolabs Network: Testing



Untitled quote 39W76M91C-V1

+ New version

Total: €8,095.00

Lock price

Go to checkout

Parts & specifications 3D printing [Change technology](#)

☐ Select all parts

Specifications

Quantity

Price

Bevel Gear Second.SLDPRT

3D printing
PA 12 (SLS)
As printed
Color: Dyed Black (default)
Layer height: 100µm

[View DFM analysis](#)

47.2 × 40.9 × 40.9 mm
22,895.175 mm3

1000

€7,820.00
€7.82p/part

Special part :
Not a common gear



Drag and drop here or [select files](#)

File types: STL, OBJ, STEP, STP, IGES, IGS, SLDPRT, 3DM, SAT, X_T

Uploading weapons or parts subject to export control regulations such as **ITAR**, **EAR** beyond EAR99, or **EU Dual** Use is a violation of our [terms of use](#)

Lead time

Economy 7 business days €7,820.00

Shipping

3-5 business days €275.00

Estimated delivery

25 December 2024

Delivered in 16 Days !

Shipping address
[Enter shipping address](#)

Billing address
[Enter billing address](#)

Subtotal €8,095.00
VAT 0% €0.00

[Have a discount code?](#)

Total €8,095.00

Fictitious quote

- 1000 Special Bevel Gear
- SLS 3D printing
- PA 12 (Nylon)
- Layer thickness ~100µm
- Size: 47x41x41mm

- Cost : 7.82 €/part
- Total: 8095 €

Additive Manufacturing Lighthouses: Benchmark for 4IR future

- **AM's Overlooked Potential in GLN:**

iAM's transformative potential is significant for manufacturing.

- **AM lighthouses importance :**

Protolabs and Fast Radius set a benchmark for the future of AM & 4IR adoption.



Challenges ?

1. Workforce upskilling
2. Resistance to change
3. Constrained budgets

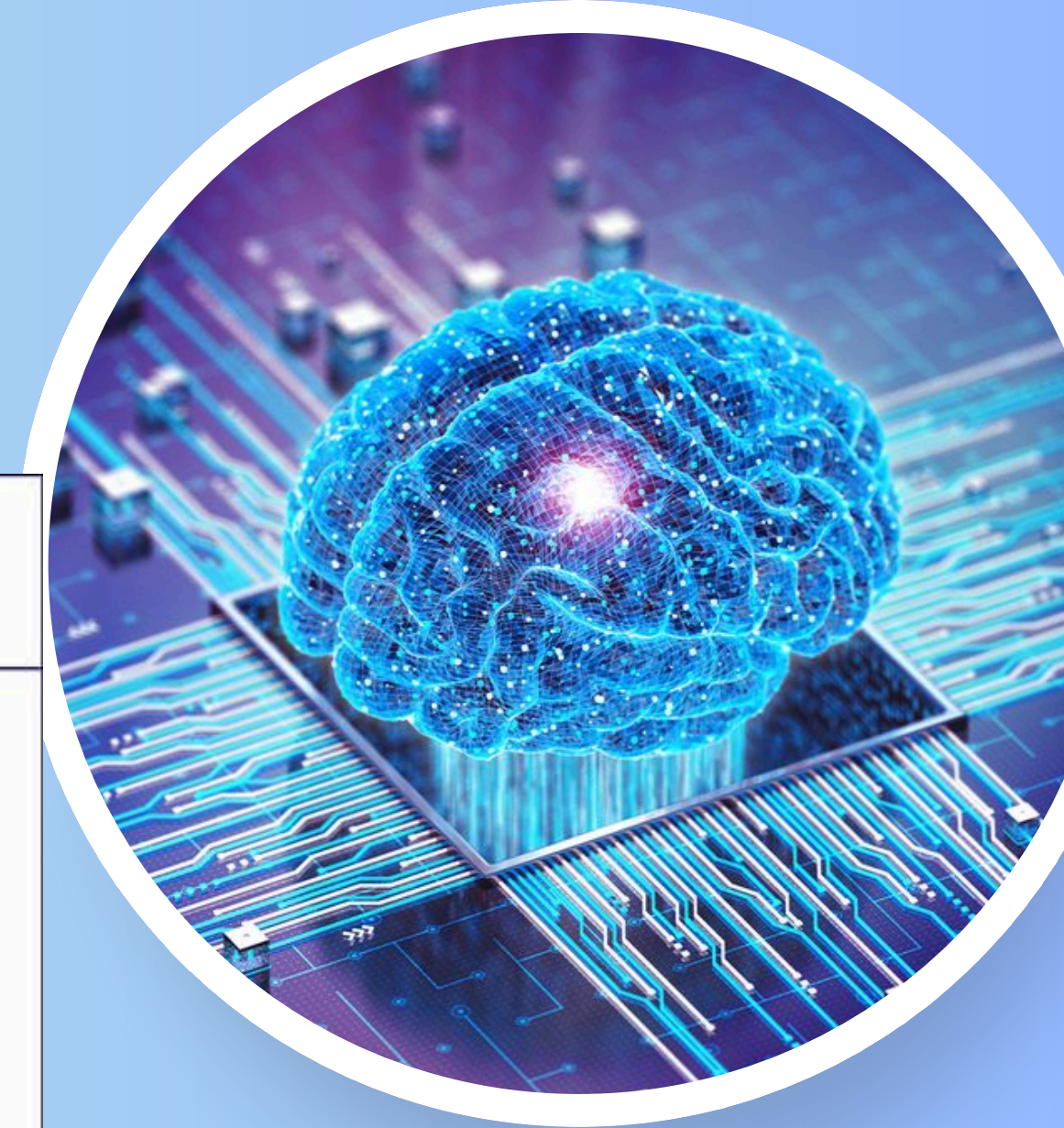
- **Expand AM Lighthouses:**

More AM lighthouses in Europe could boost AM adoption and 4IR.

Introduction AIN in ADDITIVE MANUFACTURING

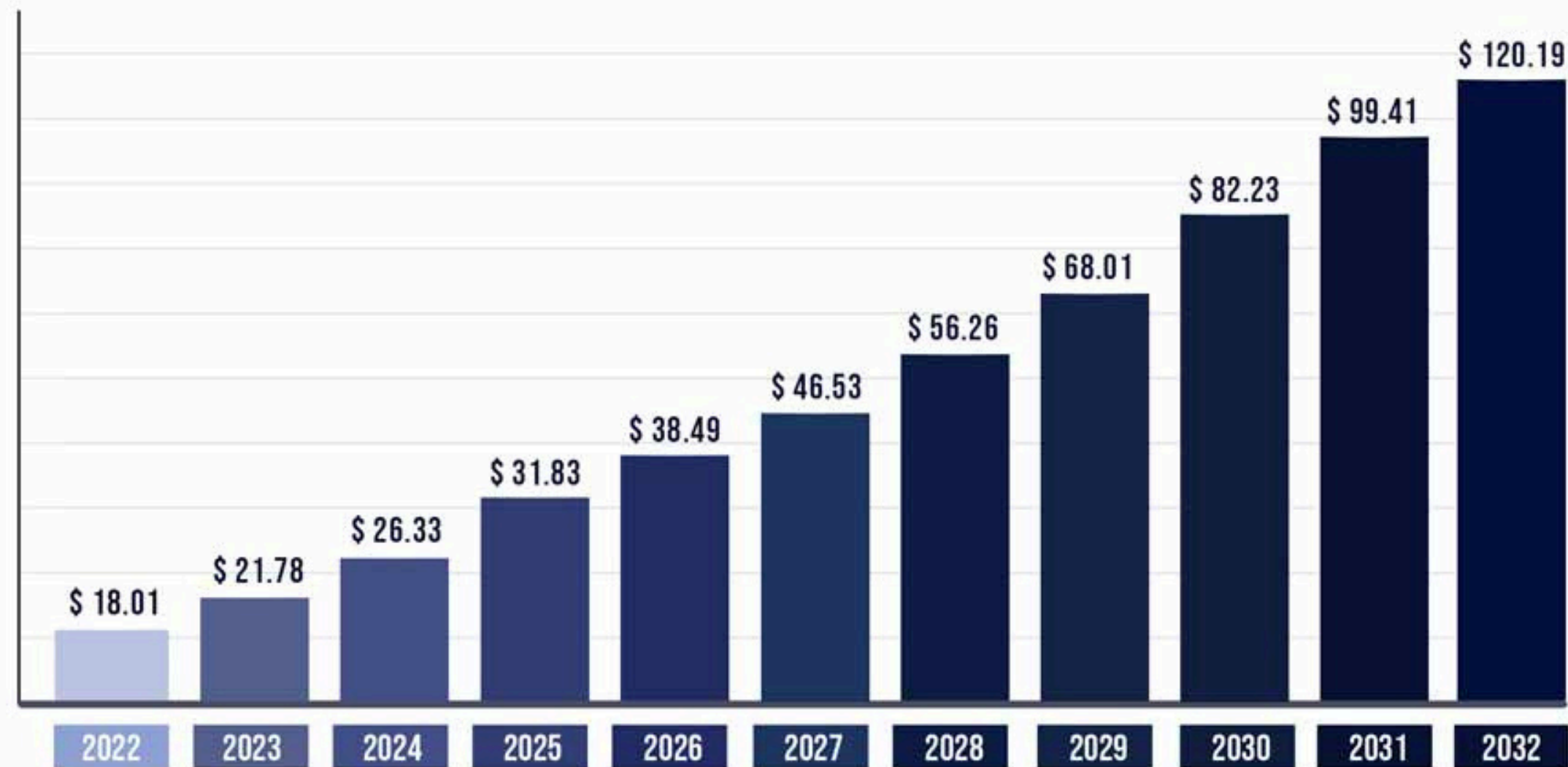


03 AI's impact on AM :

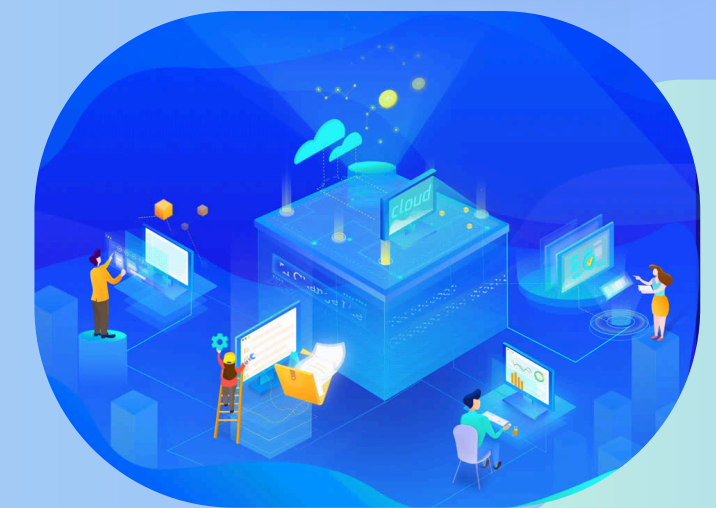


NOVA1ADVISOR

ADDITIVE MANUFACTURING MARKET SIZE, 2023 TO 2032 (USD BILLION)



Source: www.novaoneadvisor.com

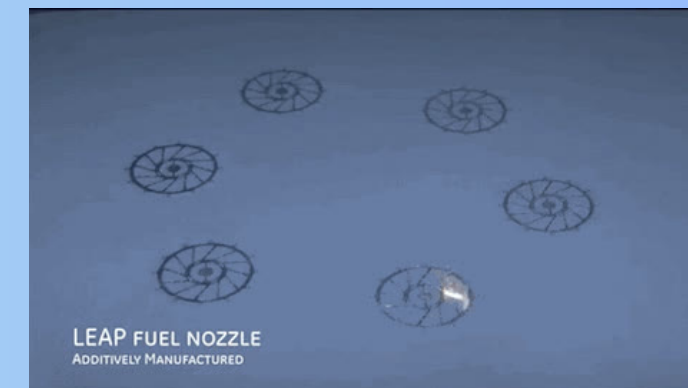


Source : <https://www.novaoneadvisor.com/report/additive-manufacturing-market>

AI in AM, Overview :



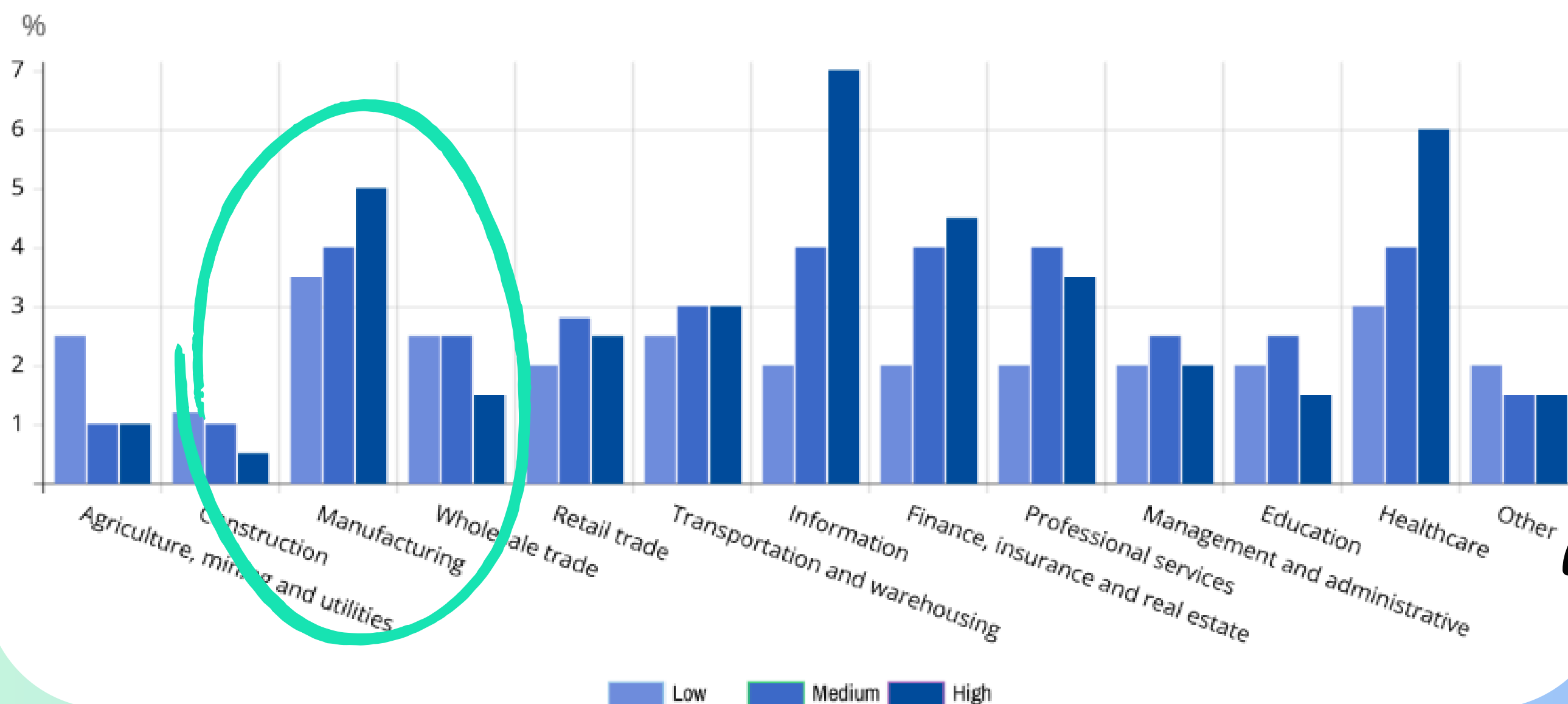
<https://raquel-mayer-kwd9.squarespace.com/blog/2018/6/25/how-many-kinds-of-3d-printing>



<https://giphy.com/gifs/ge-3d-printing-aviation-avgeek-MHyn2EeiU5THy>

AI use intensity and testing rates by sector, %

2024



How is AI used in AM

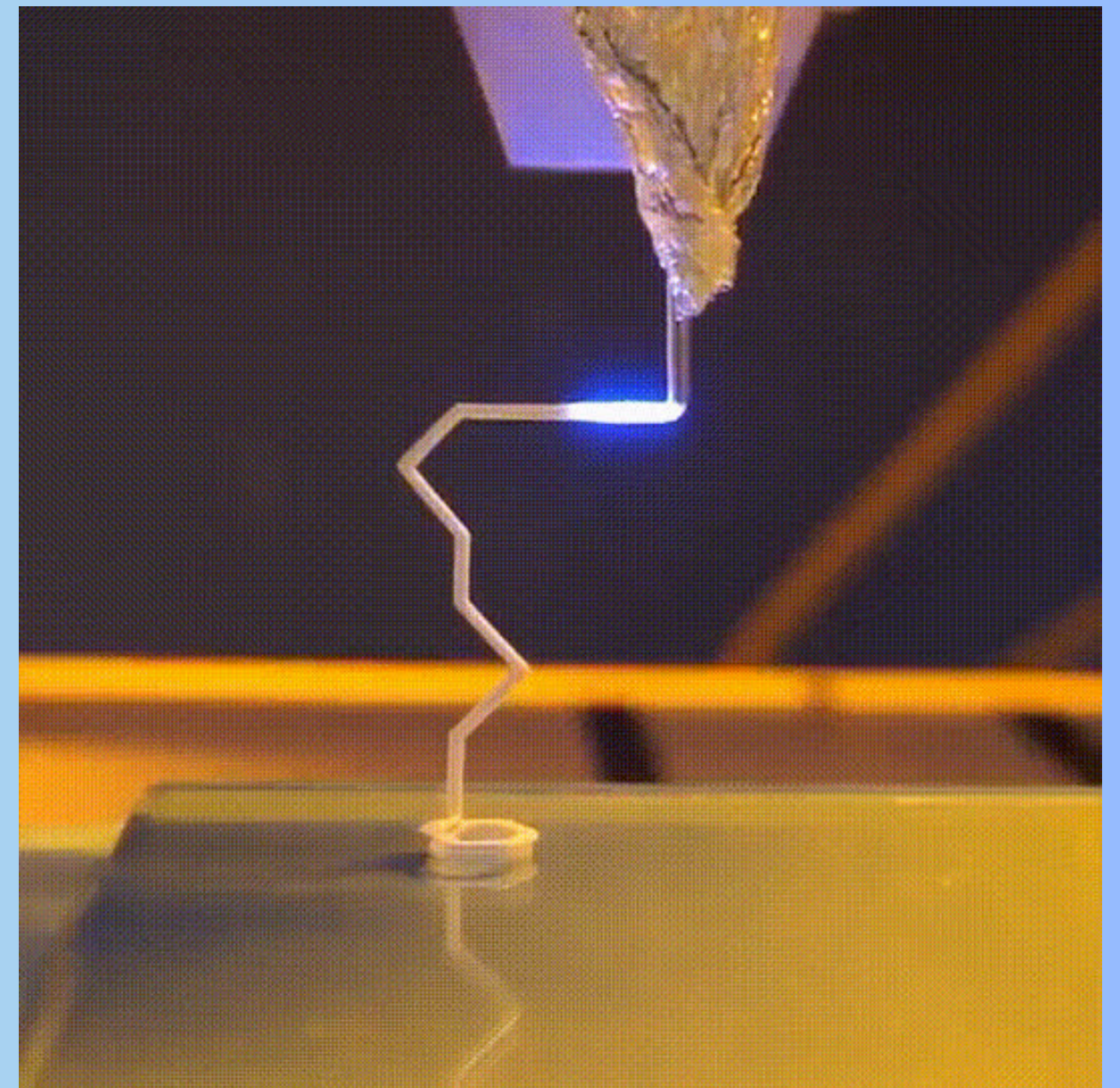
AI in extrusion-based processes :

Refresher : Extrusion-based process :

- Involves **depositing material** through a **nozzle** or **extrusion head** to create 3D objects **layer by layer**.
- **Materials used** : Thermoplastic filaments (e.g., PLA, ABS), composite pellets or pastes , metals (LMWD).
- **Techniques** : **FDM**, BPM, **LMWD**



https://makeagif.com/gif/additive-manufacturing-laser-metal-deposition-with-coaxial-wire-supply-U82_-y



<https://3dprinting.com/news/researchers-print-ceramics-in-mid-air/>

AI in extrusion-based processes : Optimization using Machine Learning :

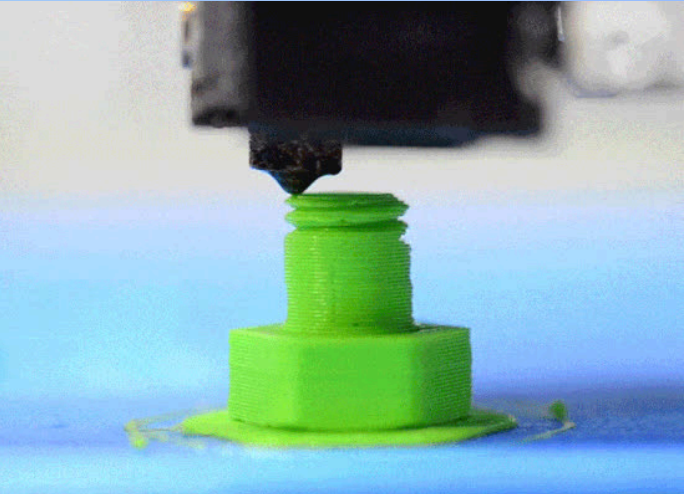
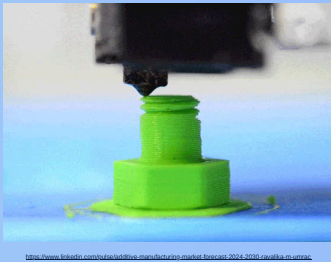


Table 1 Recent optimization and ML models for process enhancement in the FDM process

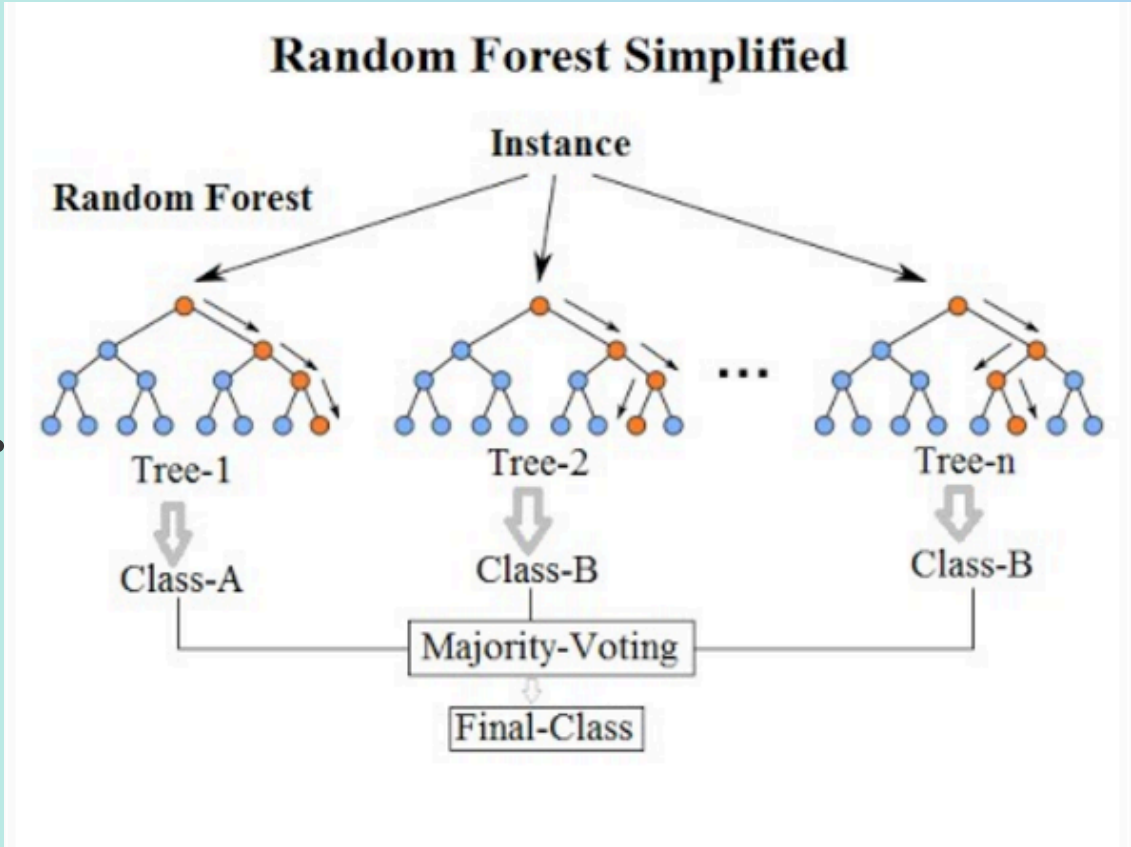
AM process	Materials	Models	Input features	ML/optimization method used	Output measured	Reference
FDM	ABS	Benchmark model	Process settings	Taguchi method	Dimensional accuracy	Mahmood et al. (2018)
FDM	PLA	ISO 527-2 tensile specimen	Process factors	Taguchi L9 method	Dimensional accuracy, part quality	Sharma et al. (2021)
FDM	PLA	Slender cuboid	Process variables	Taguchi method	Length, width, and breadth	Teng et al. (2022)
FDM	PLA	(ASTM)-D638-V	Process parameters	GA, ANN, GA_RSM	Tensile strength	Deshwal et al. (2020)
FDM	PETG	slabs	Process settings	CNN and GA	Surface roughness	Ulkir and Akgun (2023)
FFF	ABS	ASTM D638, ASTM D790 and ASTM D256	Process settings	NN	Mechanical properties	Chohan et al., (2020a, 2020b)
FFF	PLA	Benchmark model	Extruder path	GA	Print time and dimensional precision	Aguilar-Isaque et al. (2021)
FDM	PBS	cylinder	Step time, temperature	ANN, SVM, PCE, and RSM	Rheological characteristics	Taylor et al. (2023)
FFF	ABS	Infill structure	Input image	CNN	Real-time defect detection	Fahnan Khan et al. (2020)

AI in extrusion-based processes : Optimization using Machine Learning :

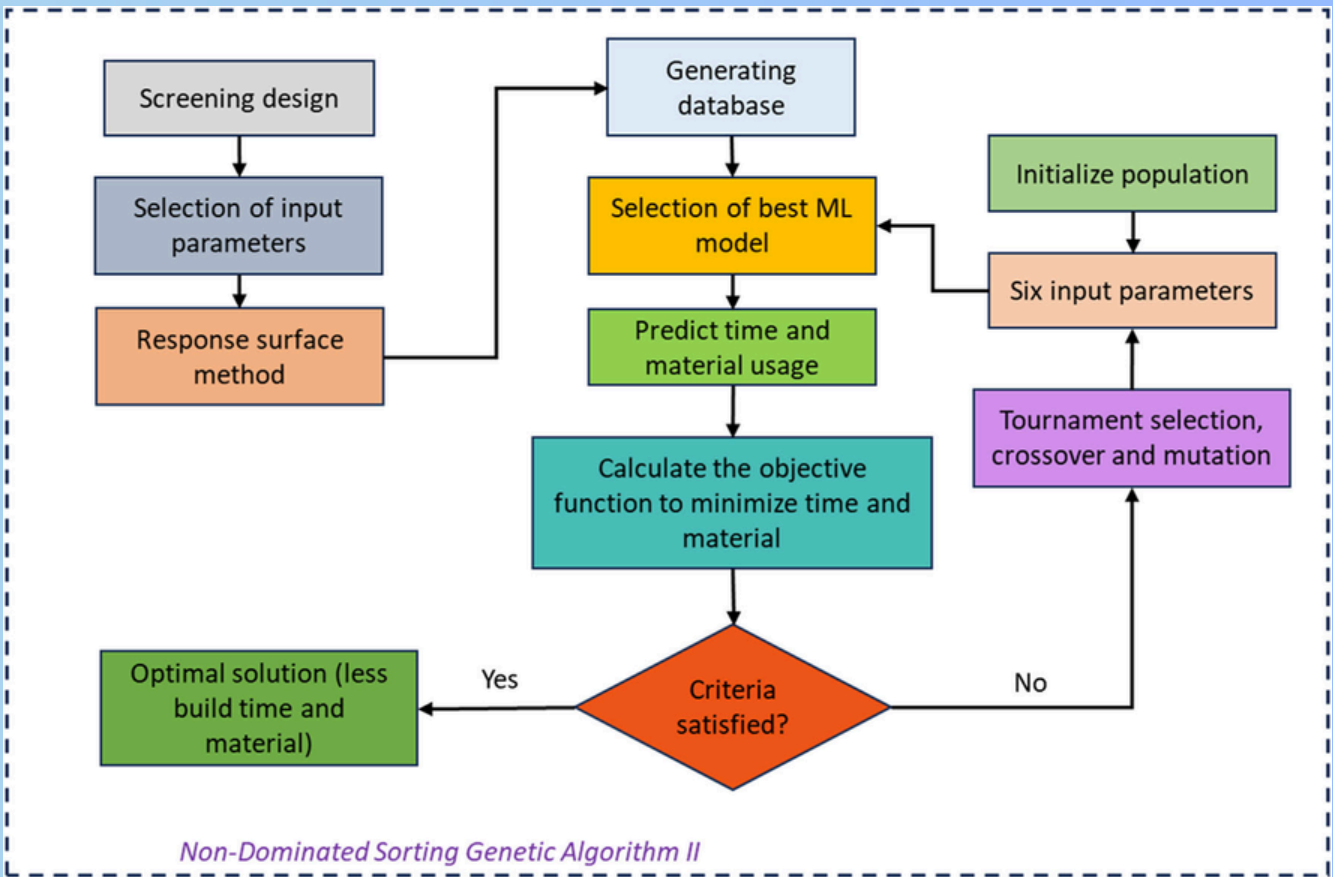
Trade-off between **build time** and **material consumption** :



S.no	Variable
1	Layer thickness
2	Build orientation
3	Infill pattern
4	STL file deviation
5	STL angle
6	Infill density
7	Raster Angle
8	Road Width
9	Contour width
10	Number of contours
11	Extrusion temperature
12	Extruder nozzle diameter
13	Printing speed
14	Travel speed



<https://williamkoebrsen.medium.com/random-forest-simple-explanation-377895a60d2d>

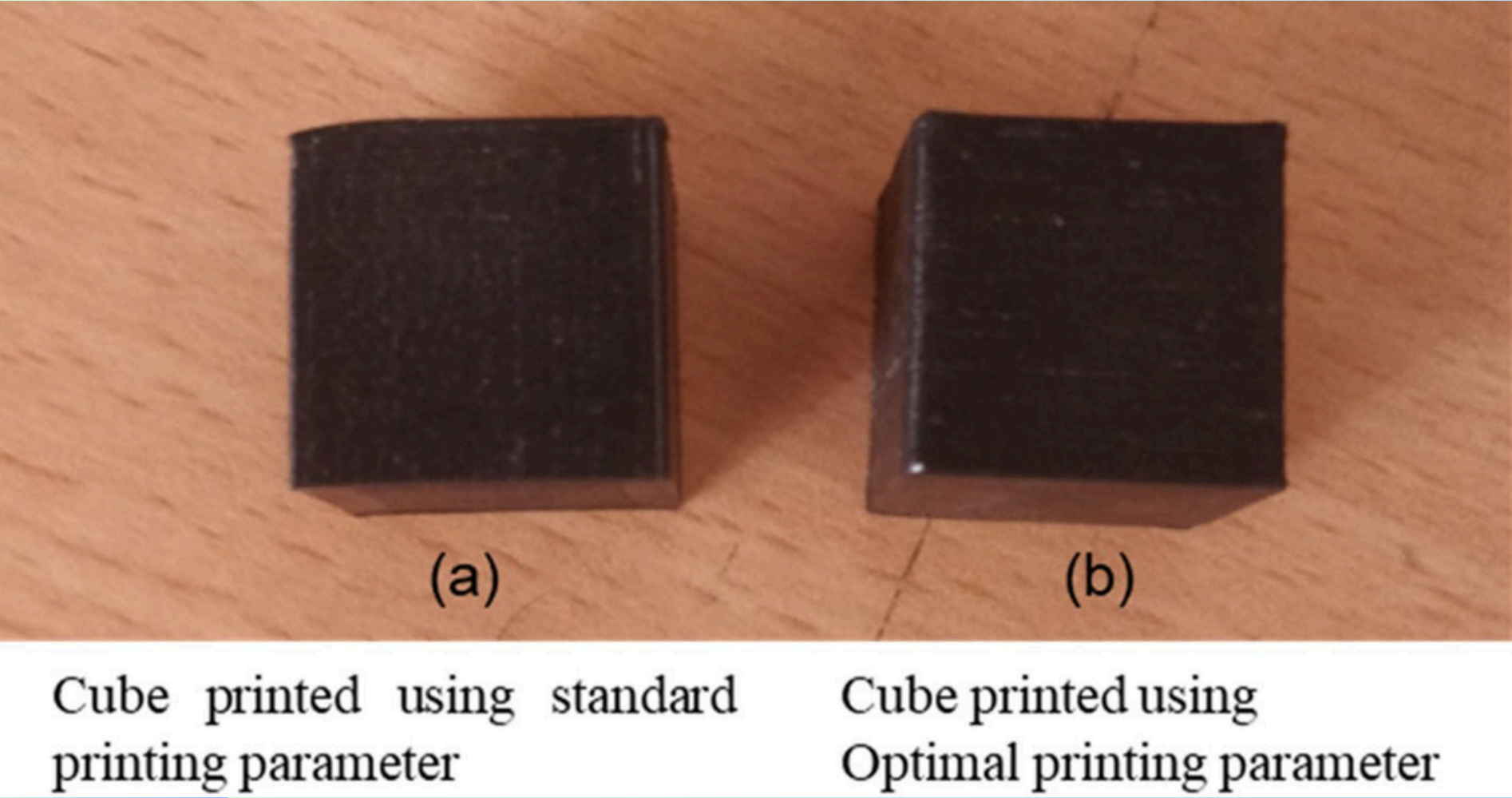


Non-Dominated Sorting Genetic Algorithm II

<https://doi.org/10.1007/s10845-024-02495-z>

AI in extrusion-based processes : Optimization using Machine Learning :

Results :



<https://doi.org/10.1007/s10845-024-02495-z>



Build time :
-37%



Material consumption :
-40%



Accuracy : (R^2)
0.96 | 0.94
Mat. consump. Build time

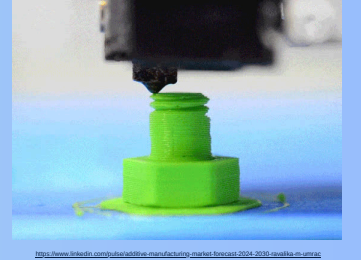
<https://doi.org/10.1007/s10845-024-02495-z>

An R^2 of 1 indicates that the regression predictions perfectly fit the data.

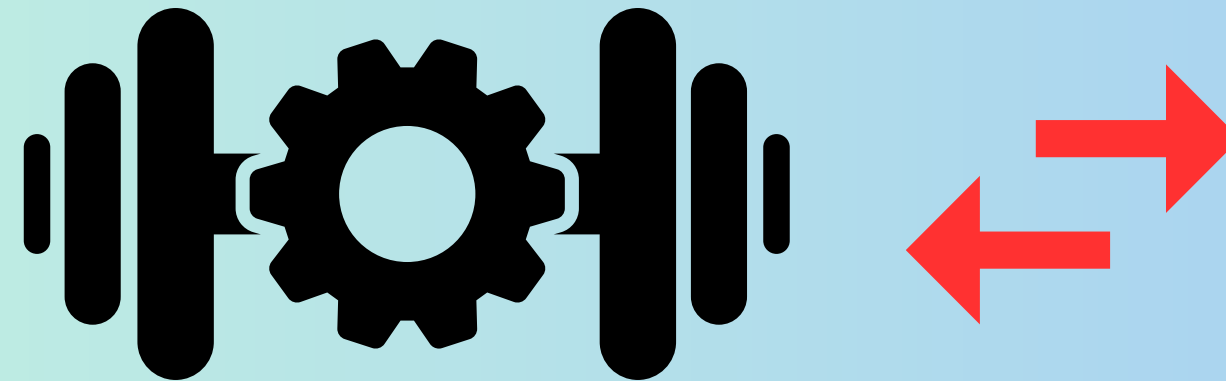
AI in extrusion-based processes :

Optimization using Machine Learning :

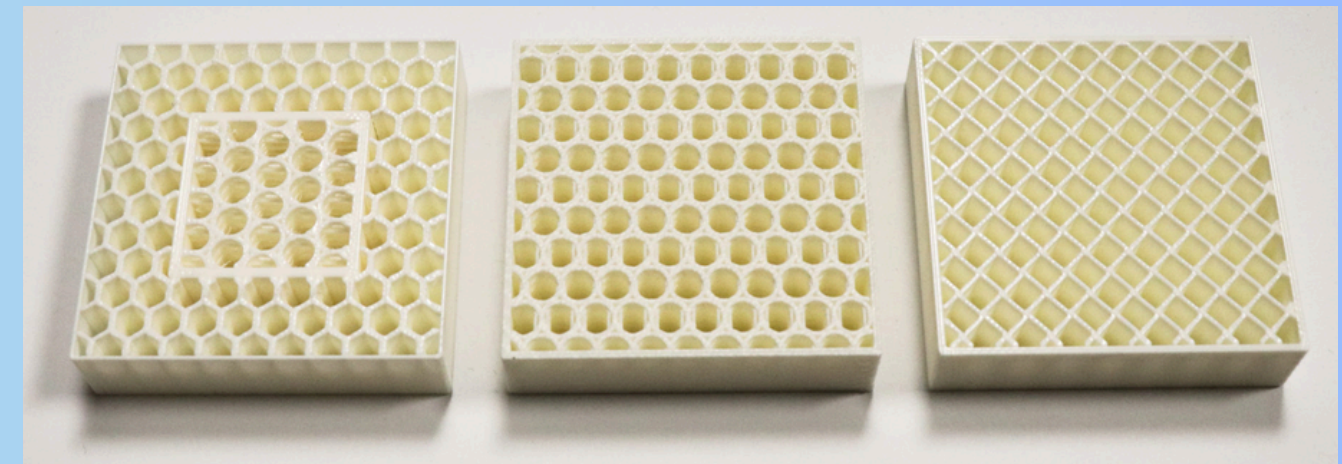
Trade-off between **build time** and **strength** :



Build time :

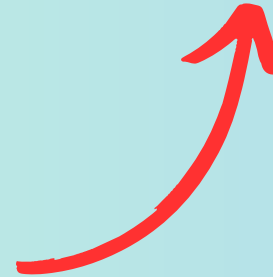
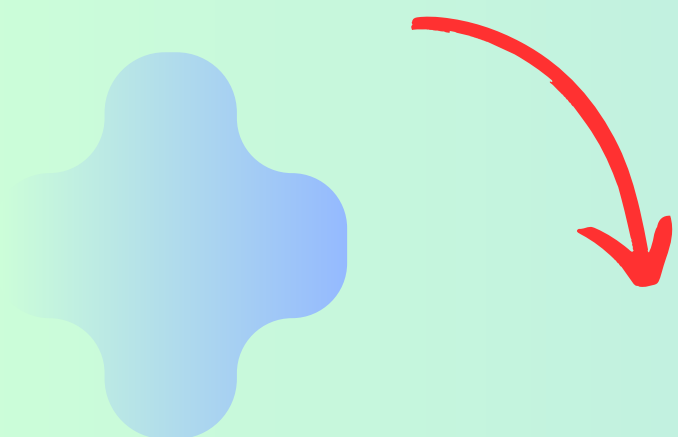


Strength :



Infill density :

%



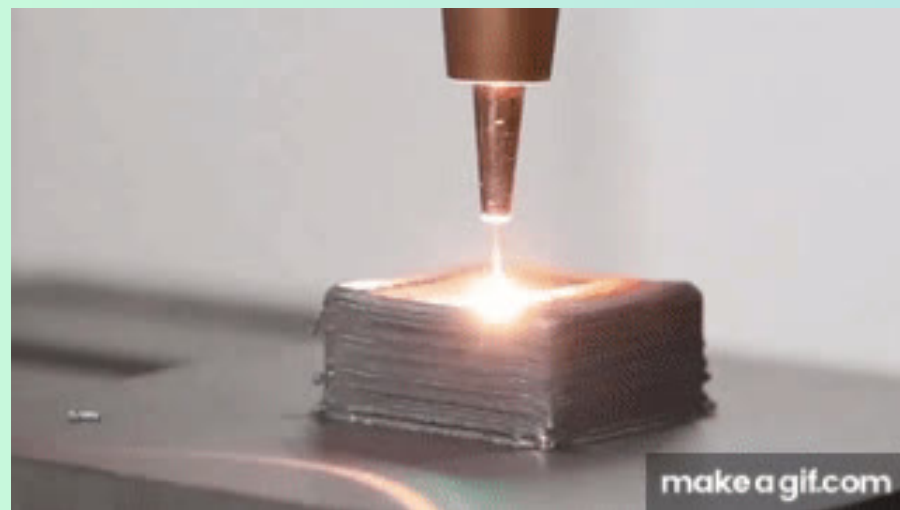
AI in extrusion-based processes :

Optimization using data-driven AI techniques :

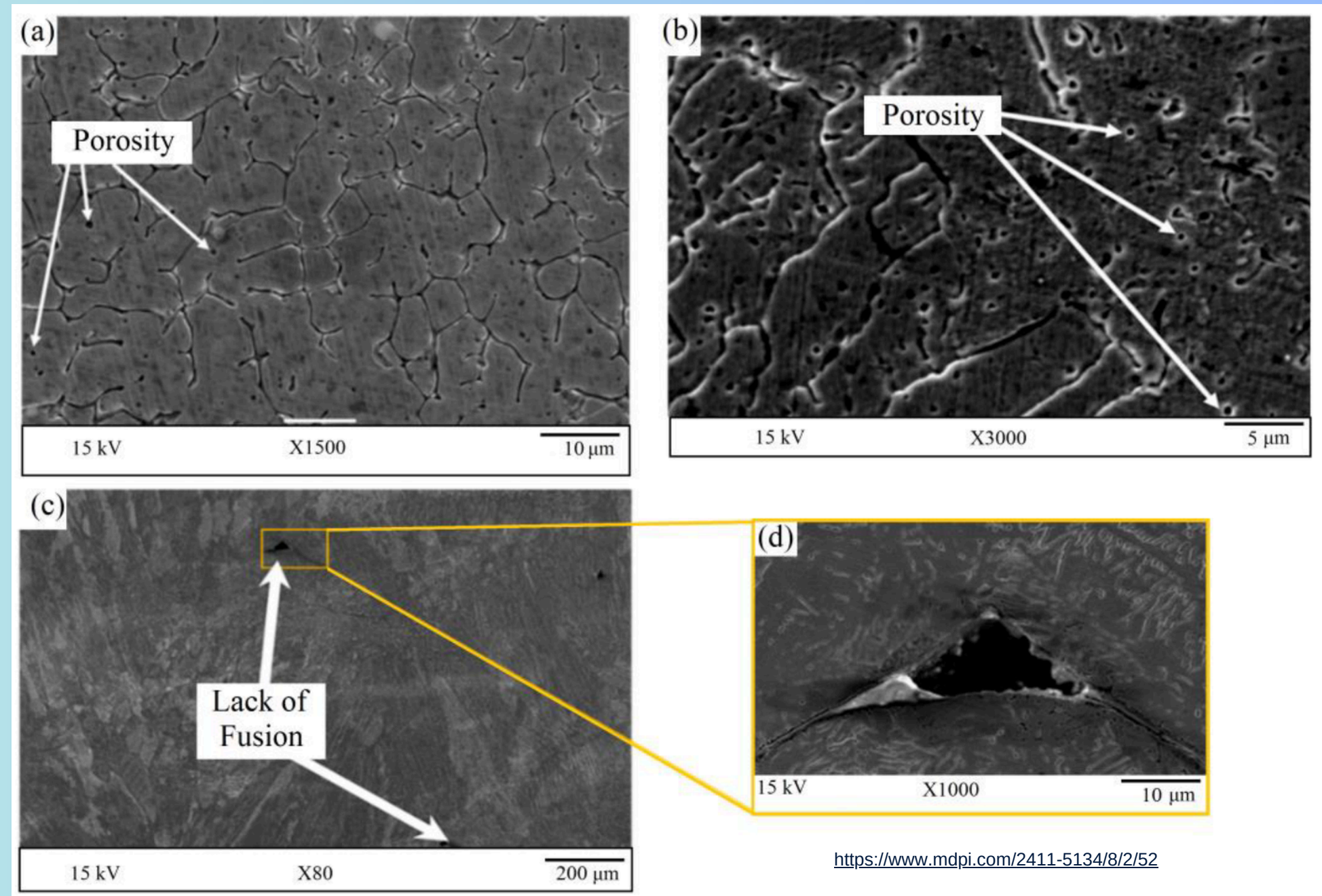
LMWD Optimizing porosity detection : Problem statement

“ However, due to the manufacturing process, the materials often have **tiny pores** inside them, which can **grow** when a load is applied, resulting in **poor quality defective parts.** ”

<https://www.sciencedirect.com/science/article/pii/S1350630723004181?via%3Dihub>



https://makeagif.com/gif/additive-manufacturing-laser-metal-deposition-with-coaxial-wire-supply-U82_y



<https://www.mdpi.com/2411-5134/8/2/52>

AI in extrusion-based processes :

Optimization using data-driven AI techniques :

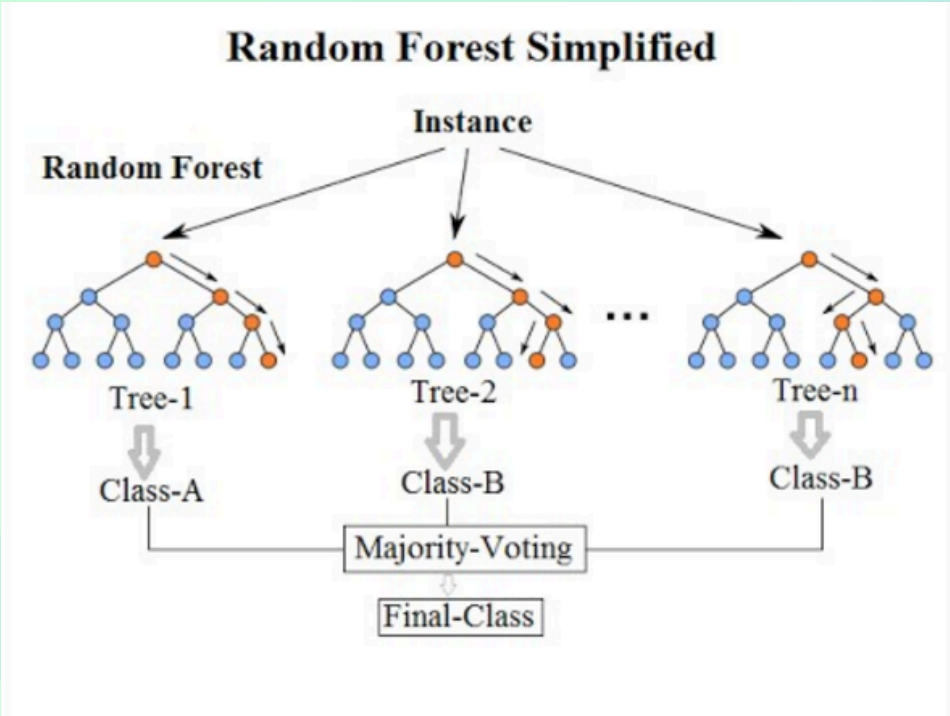
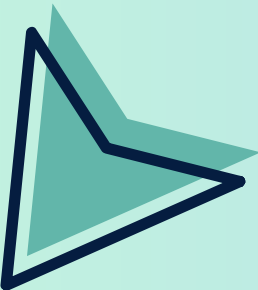
Optimizing porosity detection :

Laser power

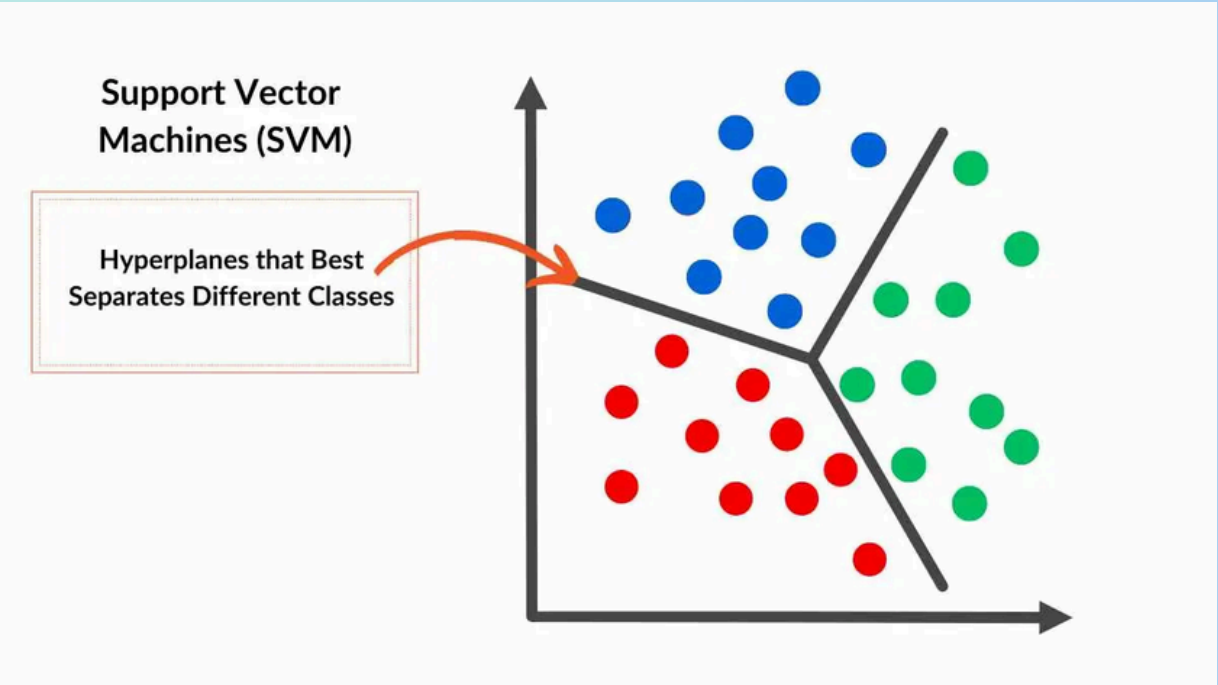
Movement velocity

Wire feed rate

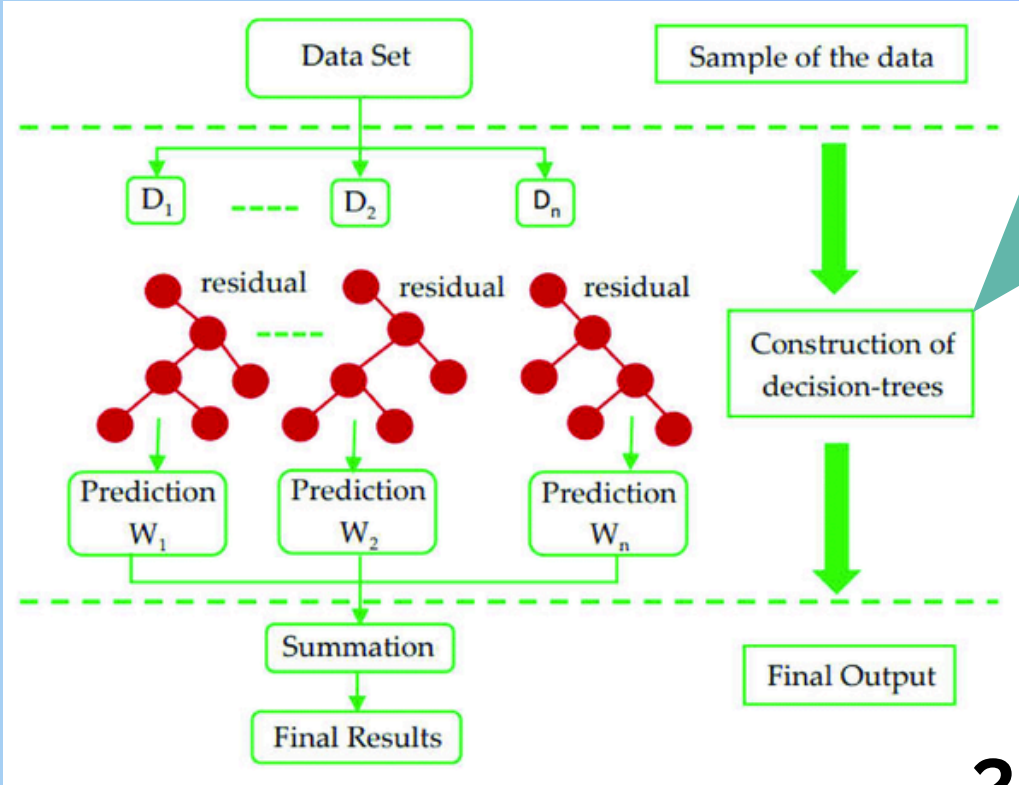
Input (optimized) parameters :



<https://williamkoehrsen.medium.com/random-forest-simple-explanation-377895a60d2d>



<https://spotintelligence.com/2024/05/06/support-vector-machines-svm/>



https://www.researchgate.net/figure/GBoost-extreme-gradient-boosting-algorithm-structure-31_fig2_362325316

AI in extrusion-based processes :

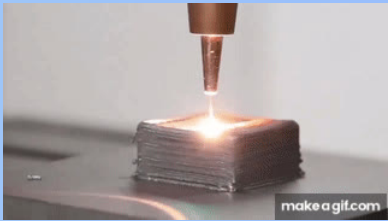
Optimization using data-driven AI techniques :

Optimizing porosity detection :

Validation Partition	Algorithm	Local Class	
		Accuracy	Recall
2/3 part to train and 1/3 part to test	KNN	0.954	0.855
	SVM	0.959	0.855
	RF	0.937	0.818
	XGBoost	0.964	0.804
2/3 total to train and 1/3 total to test	KNN	0.971	0.742
	SVM	0.956	0.762
	RF	0.914	0.728
	XGBoost	0.972	0.694
2 parts to train and 1 part to test	KNN	0.969	0.393
	SVM	0.966	0.034
	RF	0.903	0.267
	XGBoost	0.975	0.021

Porosity detection
& prevention

in real time, with high
accuracy and recall



<https://makeagif.com/gif/additive-manufacturing-laser-metal-deposition-with-coaxial-wire-supply-LB2-y>

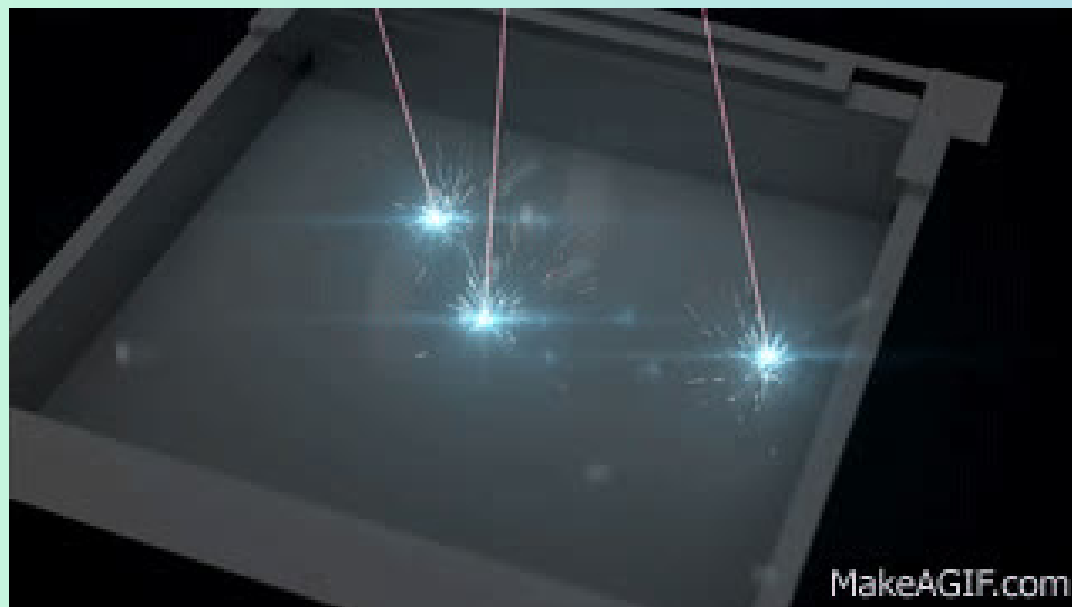
AI in powder-based processes :

Refresher : Powder-based process :

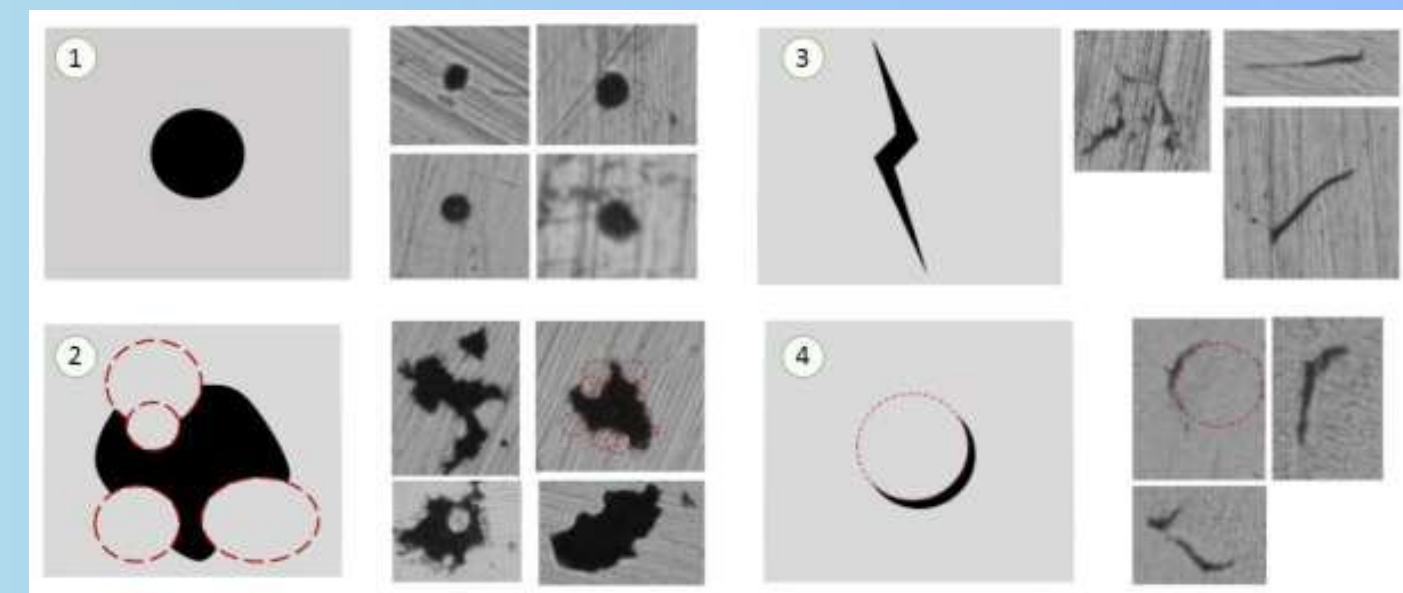
- Powder based processes involve **bonding powdered materials** to form solid parts. This bonding can be achieved either by **applying heat** to **partially** or **fully melt** and **fuse** the powder particles or by using a **binding agent** to adhere the particles together.
- **Techniques : BJ** (binder), **PBF** (LB (SLS, **SLM**), EB, IR)



<https://makeagif.com/gif/new-method-of-manufacturing-using-powder-bed-additive-manufacturing-with-selective-laser-melting-ehBvzO>



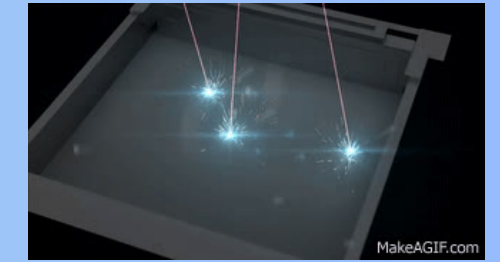
<https://makeagif.com/gif/slm-solutions-selective-laser-melting-MTpWDb>



https://www.researchgate.net/figure/Defects-formed-during-SLM-The-first-type-of-pores-Figure-2-1-can-be-designated-as-gas_fig2_356116313

AI in powder-based processes :

Optimization using data-driven AI techniques :

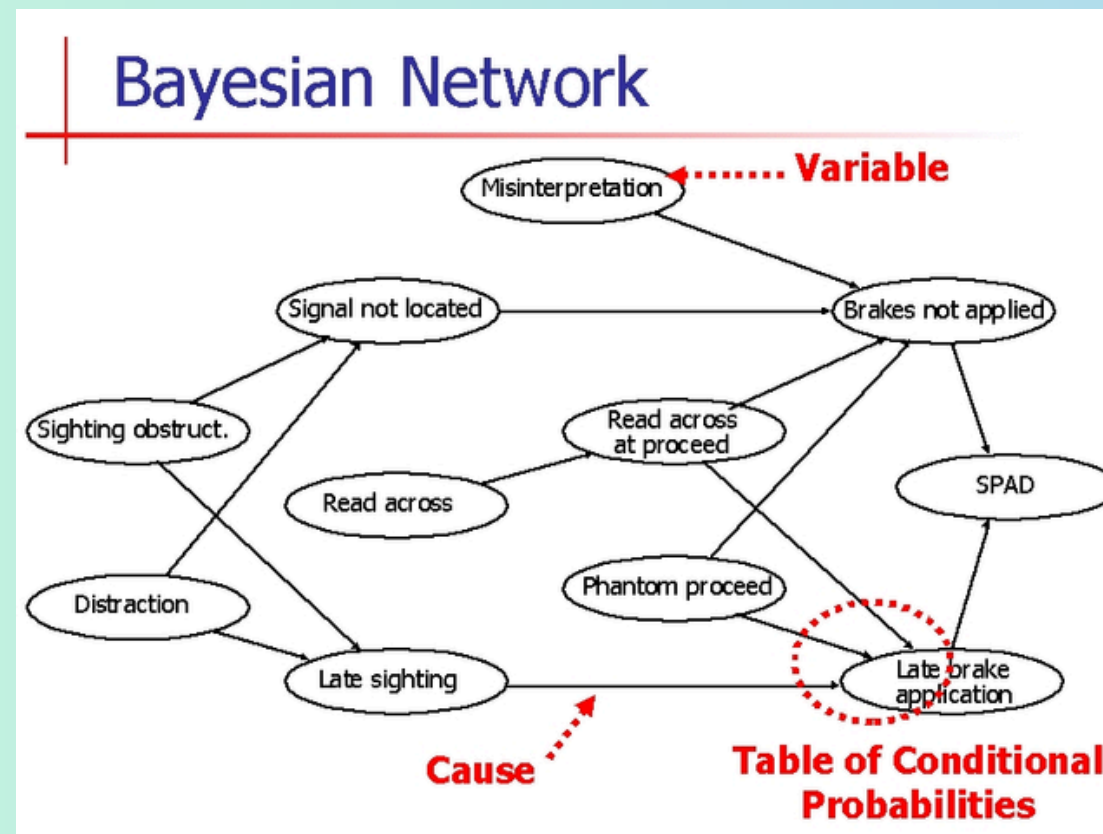


<https://makeagif.com/gif/sim-solutions-selective-laser-melting-MTqWDh>

Input (optimized) parameters :

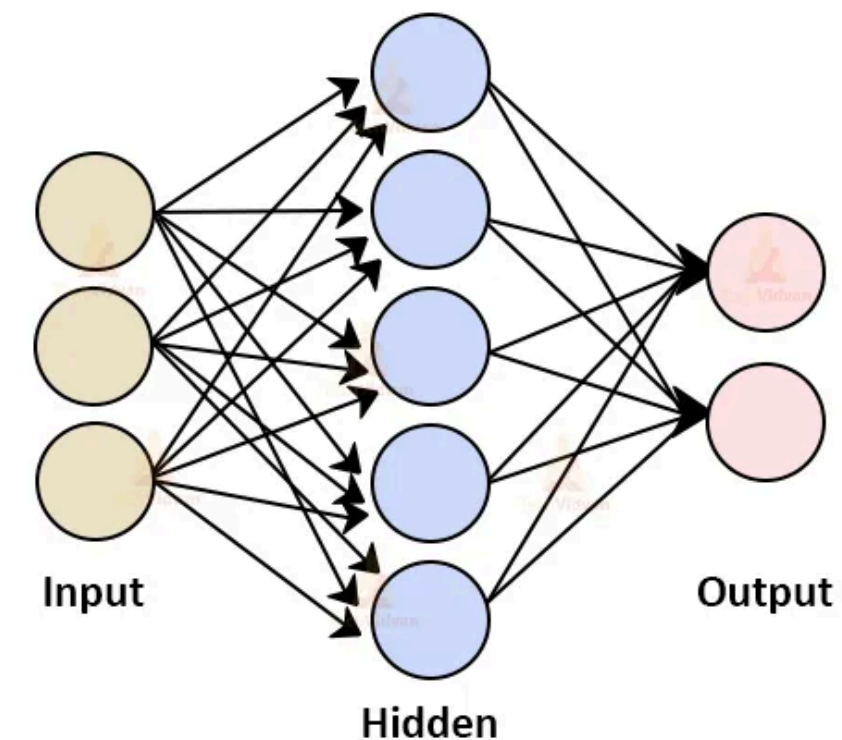
Laser power | Scan speed | Layer speed | Hatch spacing*

*:It is the spacing between the centers of two adjacent beams



<https://www.eecs.qmul.ac.uk/~william/PSAM7/img7.html>

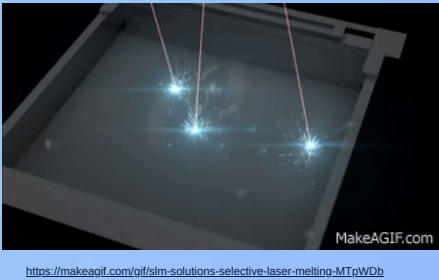
Architecture of Artificial Neural Network



<https://blog.knoldus.com/architecture-of-artificial-neural-network/>

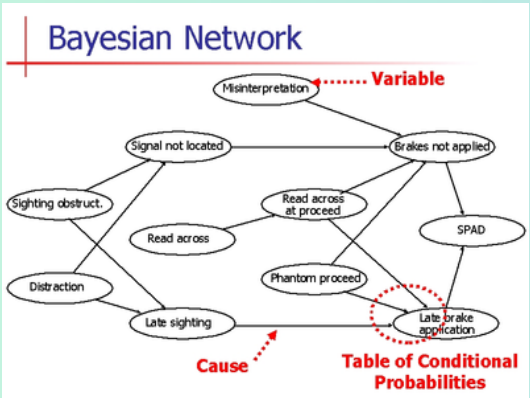
AI in powder-based processes :

Optimization using data-driven AI techniques :



Results :

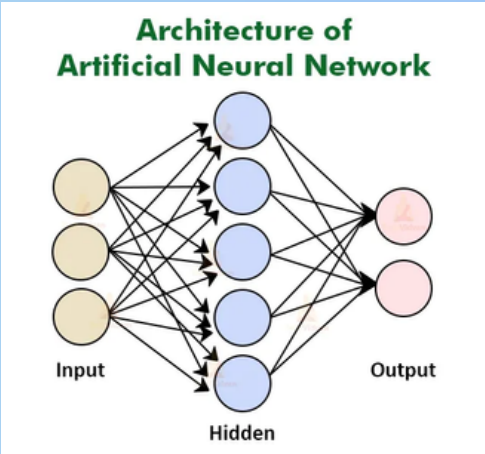
BN



**Prediction
part density**

99%

ANN



Prediction errors

surface roughness

<4.4%

density

<0.98%

04

Digital twins

Marko Mitric - 315718

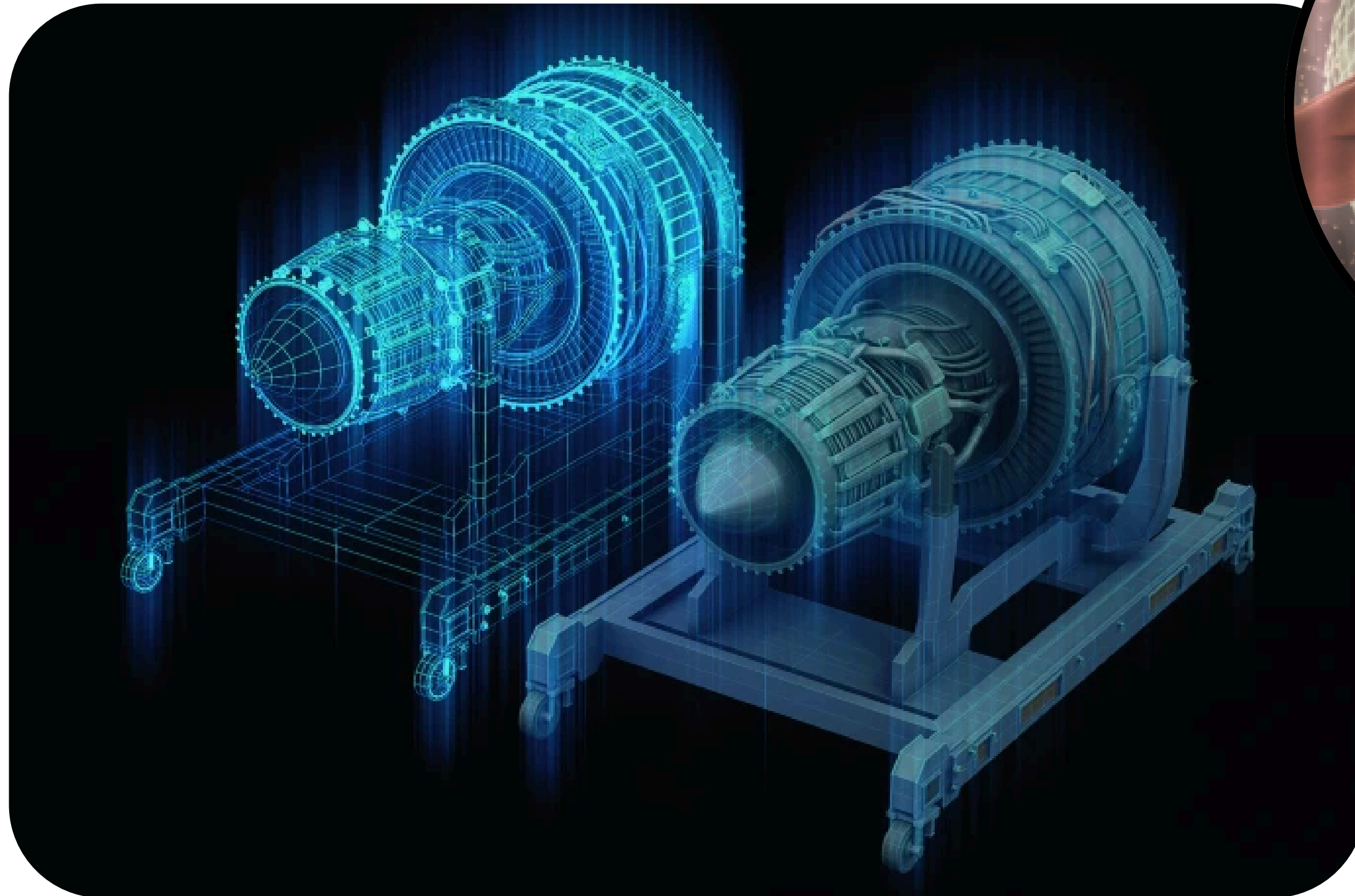
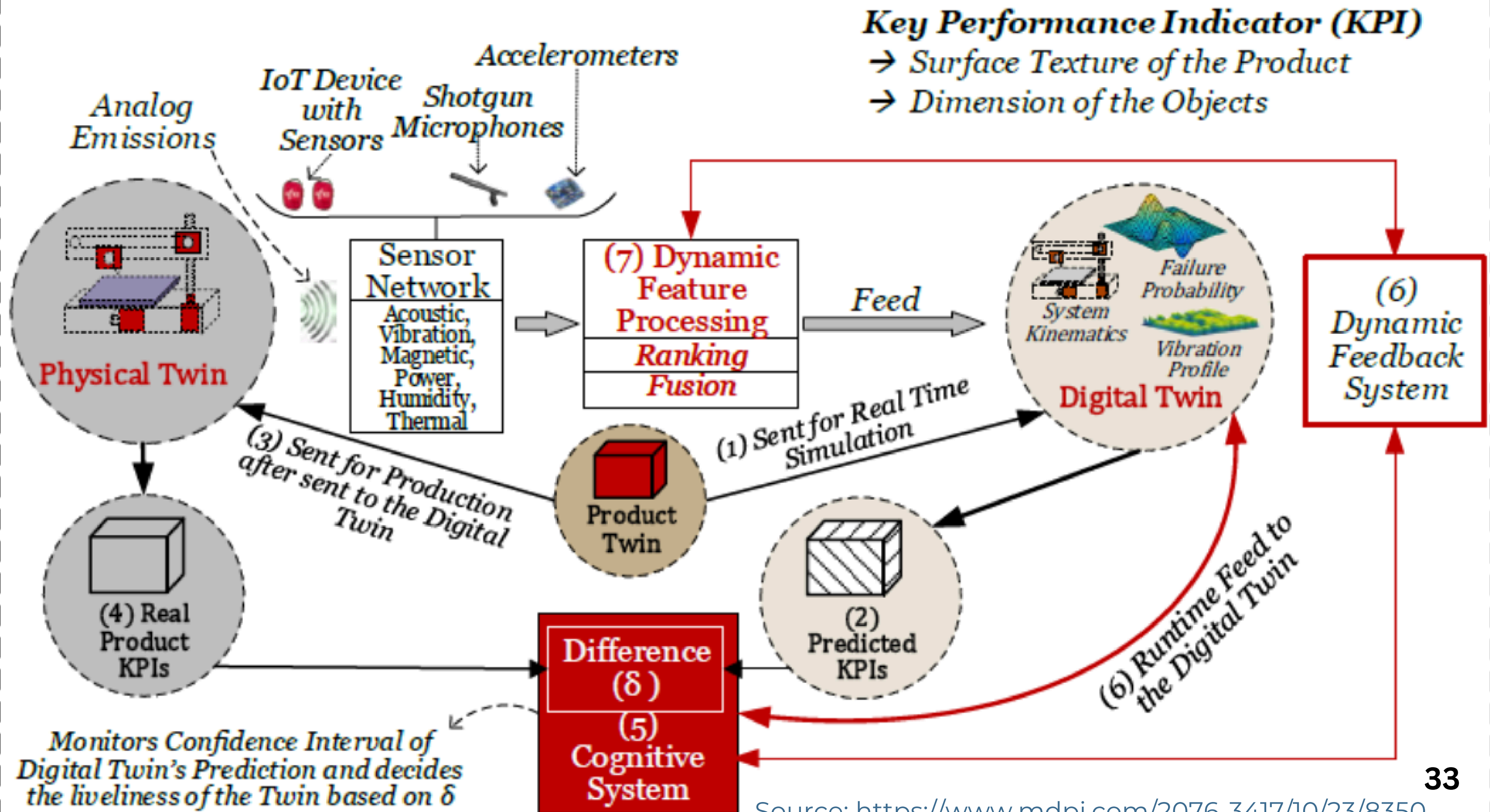


illustration from <https://www.nature.com/articles/s43588-024-00617-4>
<https://www.photonicsonline.com/doc/understanding-digital-twins-in-metrology-0001>

Digital twins

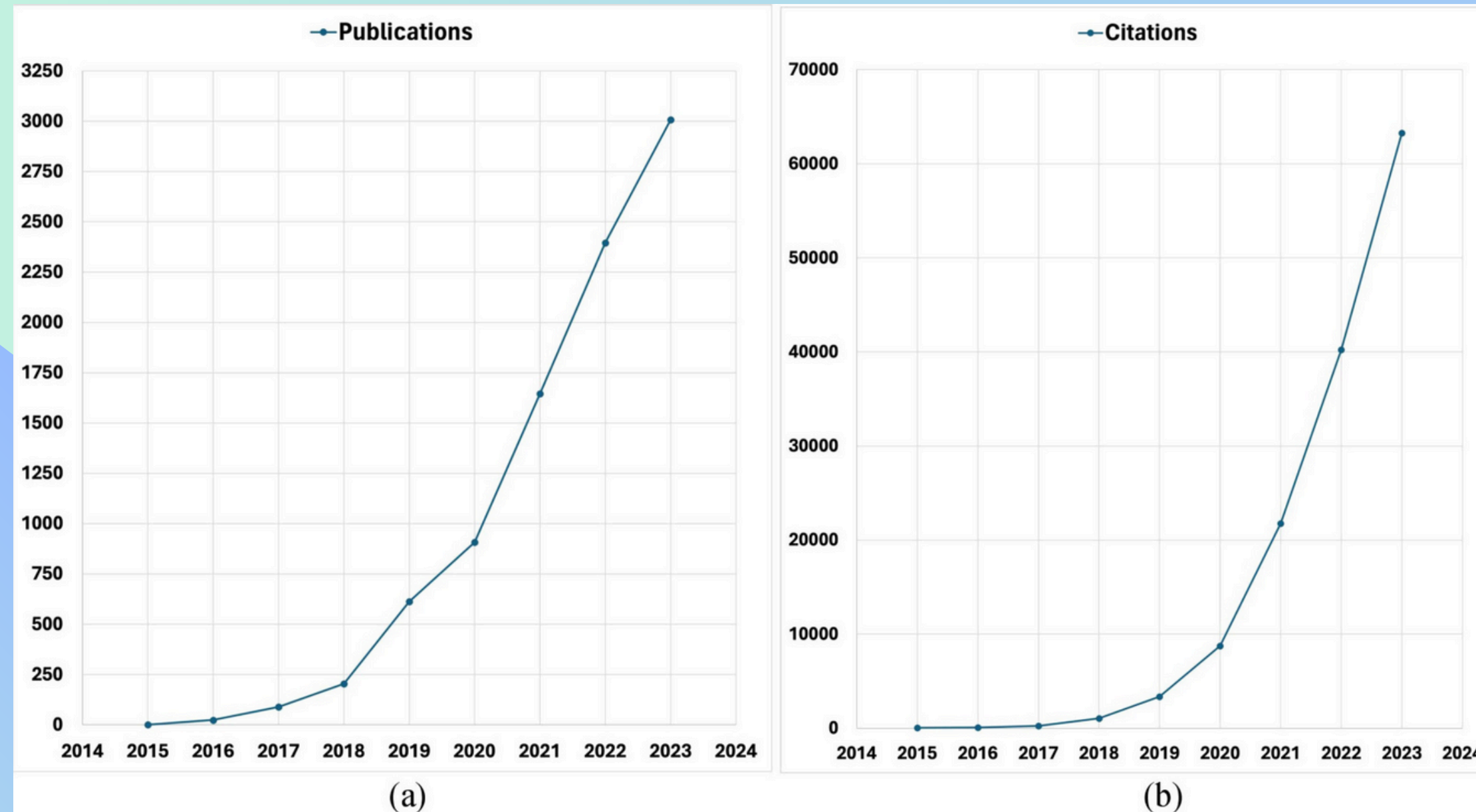
One definition

A **digital twin** is a set of virtual information constructs that **mimics the structure**, context, and **behavior** of a natural, engineered, or social system (or system-of-systems), is **dynamically updated** with data from its **physical twin**, has a **predictive capability**, and informs decisions that realize value. The **bidirectional interaction** between the virtual and the physical is central to the digital twin.



A new domain

In additive manufacturing



Source: <https://www.sciencedirect.com/science/article/pii/S2588840424000556>!

Technologies of DT

A mix of recent technologies

Internet of Things

IoT sensor that allow constant data transmission

Extended Reality

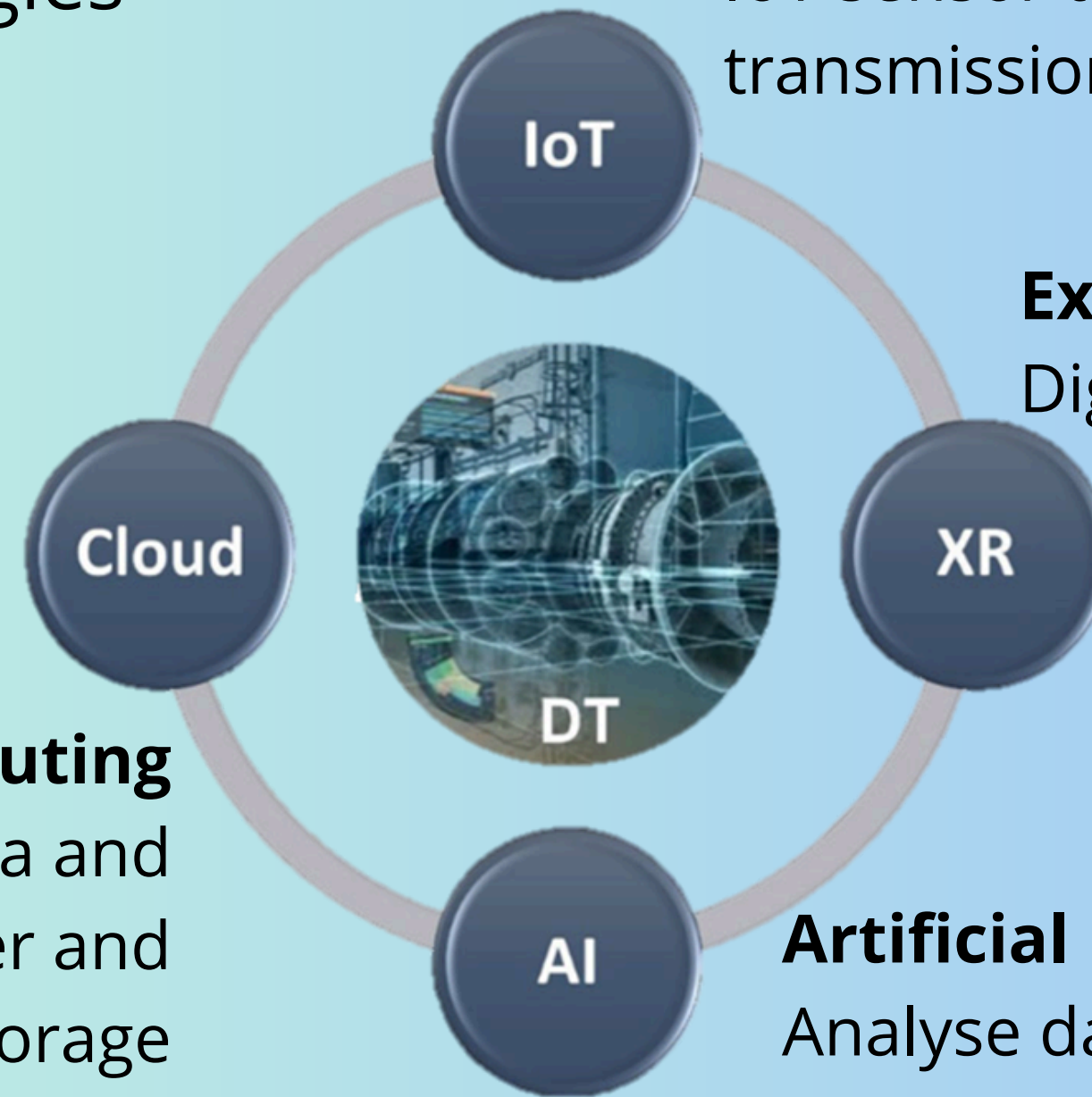
Digitally represent a physical object

Artificial Intelligence

Analyse data, provide insights and make predictions

Cloud Computing

Manage large amounts of data and offers computational power and storage



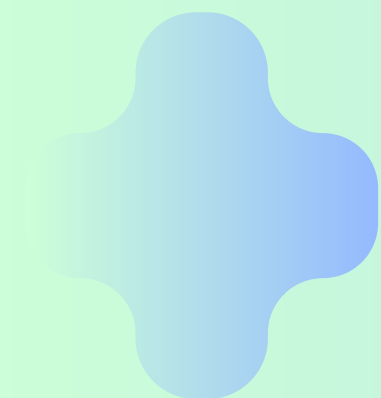
Source: <https://link.springer.com/article/10.1007/s43674-023-00058-y>

Application on a FDM 3D printer

Paper: *"Integrating Machine Learning Model and Digital Twin System for Additive Manufacturing"*

<https://ieeexplore.ieee.org/abstract/document/10179224>

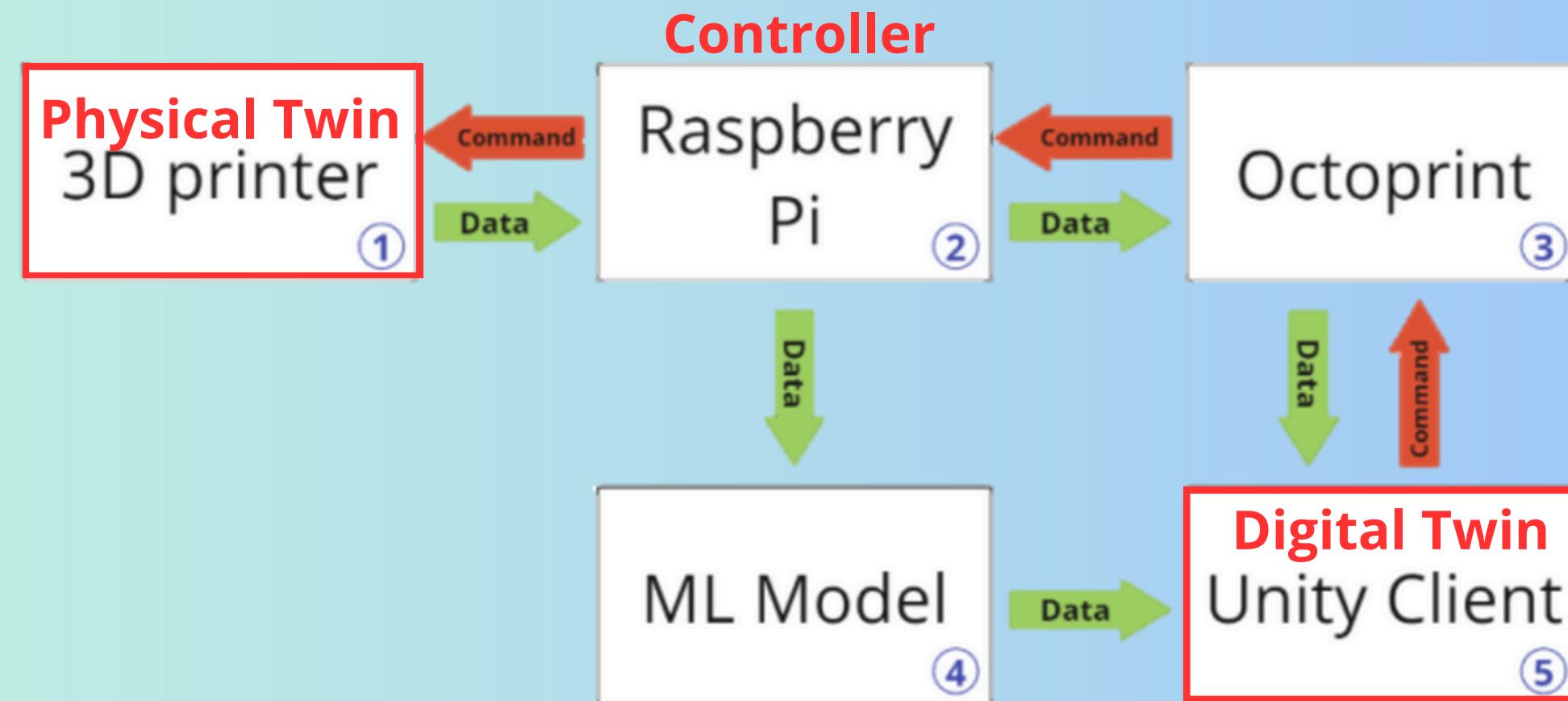
- Embedded sensors to generate 3D model
- Camera and machine learning for defect detection
- Autonomously stop the printer if defect occurs



Application - 3 characteristics of DT

- Bi-directional communication
- Real time monitoring/control
- A certain level of intelligence

Implementation:



<https://ieeexplore.ieee.org/abstract/document/10179224>

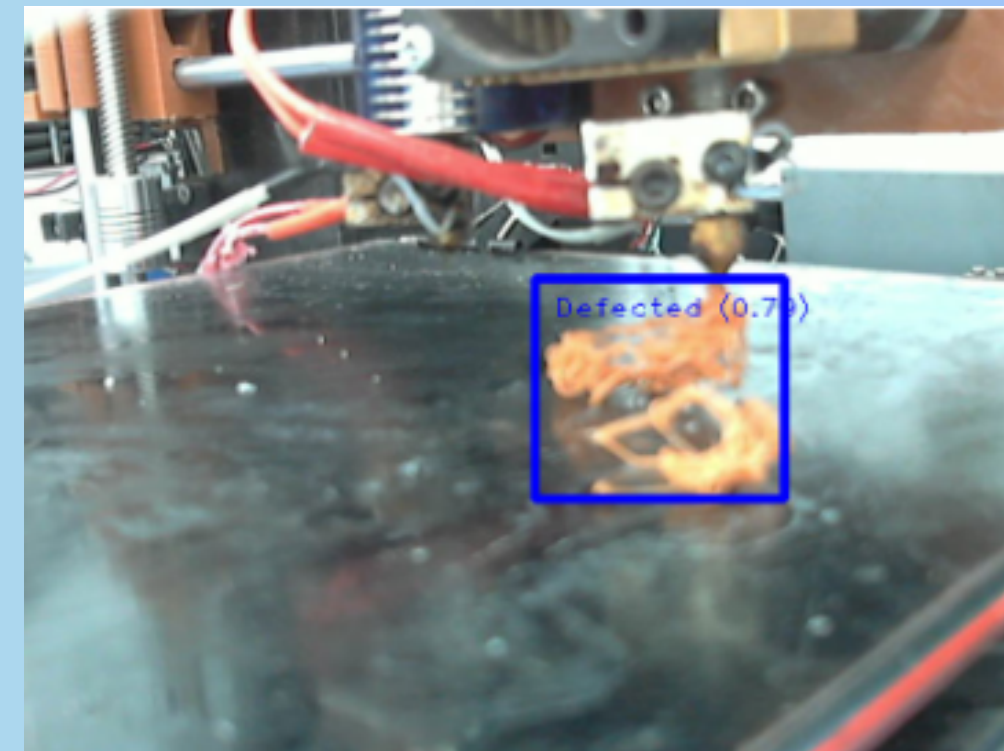
Application - Results

Detection of printing defects with an average accuracy of **92.34%**

Automatically stop the process as soon as error is detected.

Achieved 3 main goals:

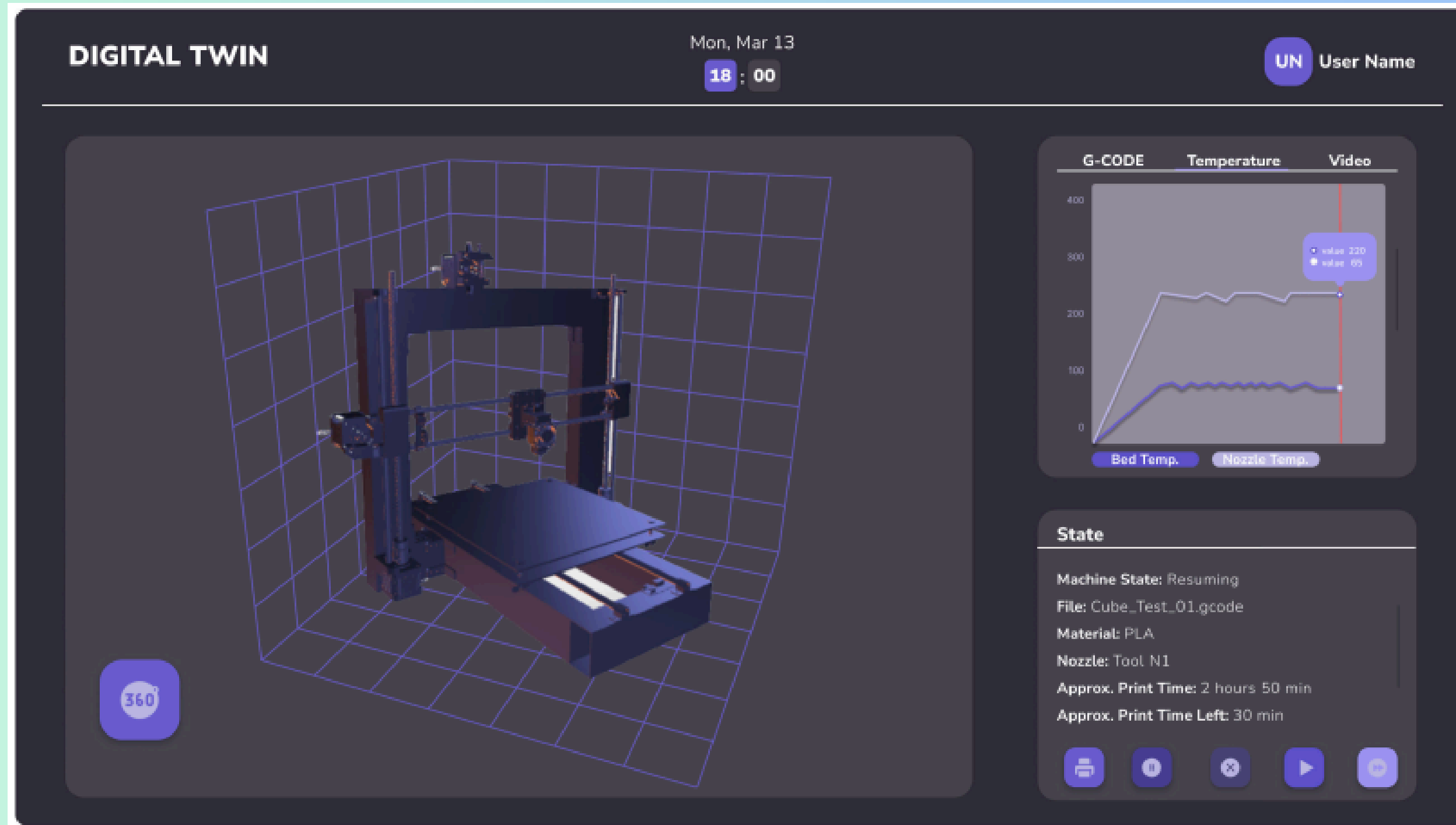
- Bi-directional communication
- Real time monitoring/control
- A certain level of intelligence



<https://ieeexplore.ieee.org/abstract/document/10179224>

Application

DT User Interface



<https://ieeexplore.ieee.org/abstract/document/10179224>

Discussion

Digital twins are promising but are still in the development phase. They have the potential to solve some issues of AM.

Enhance simulation by monitor other physical properties
Computational challenge to model more involved physics

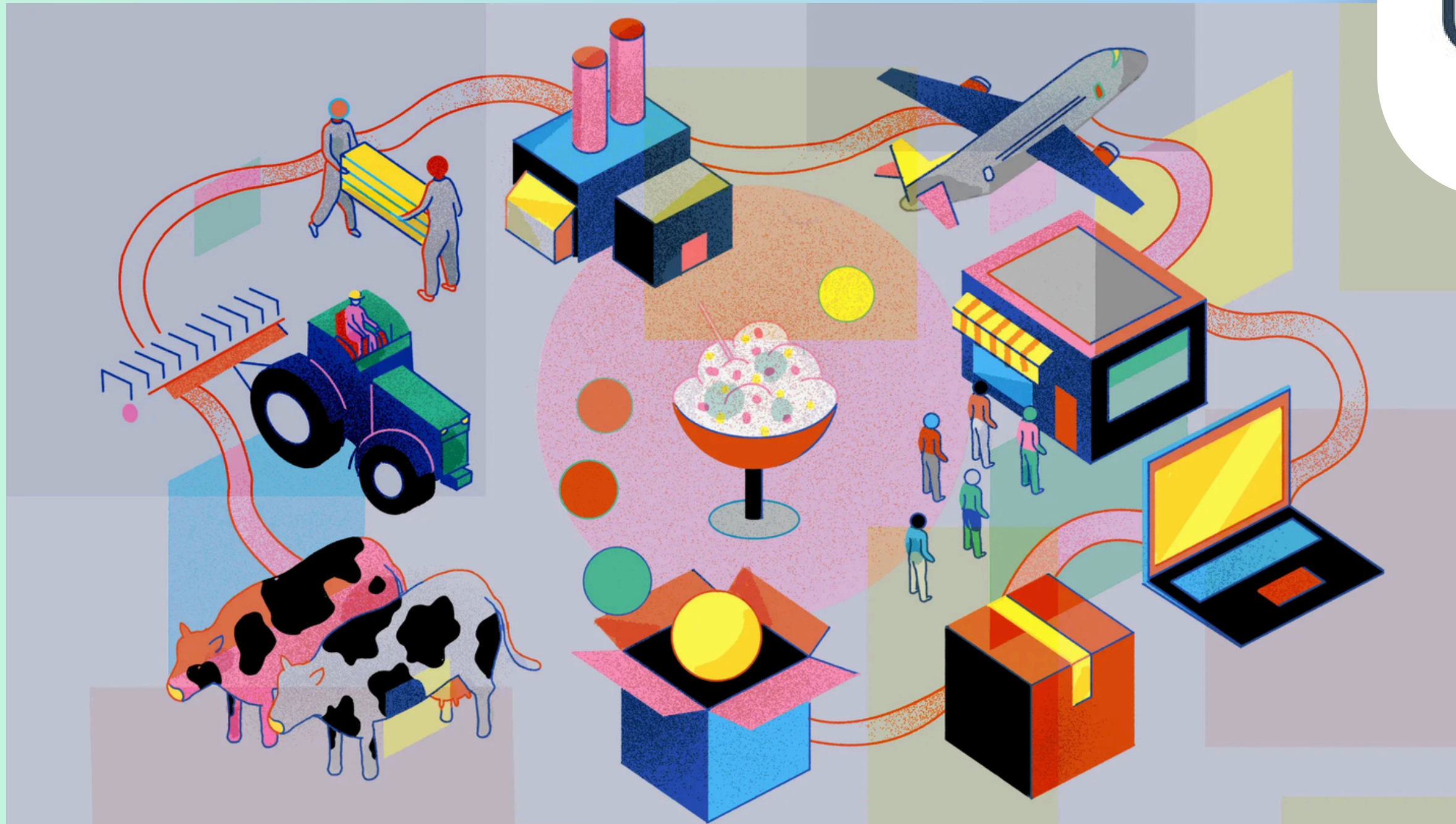
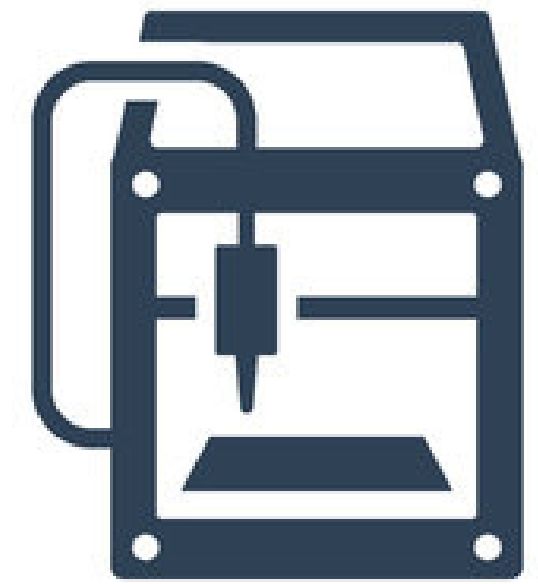
Data collection challenges
Due to various data types and protocols across sensors

Development of Digital twins for other AM processes
There is some research on DT for powder based AM

05

AM and Smart manufacturing

Adrien Maitrot - SCIPER

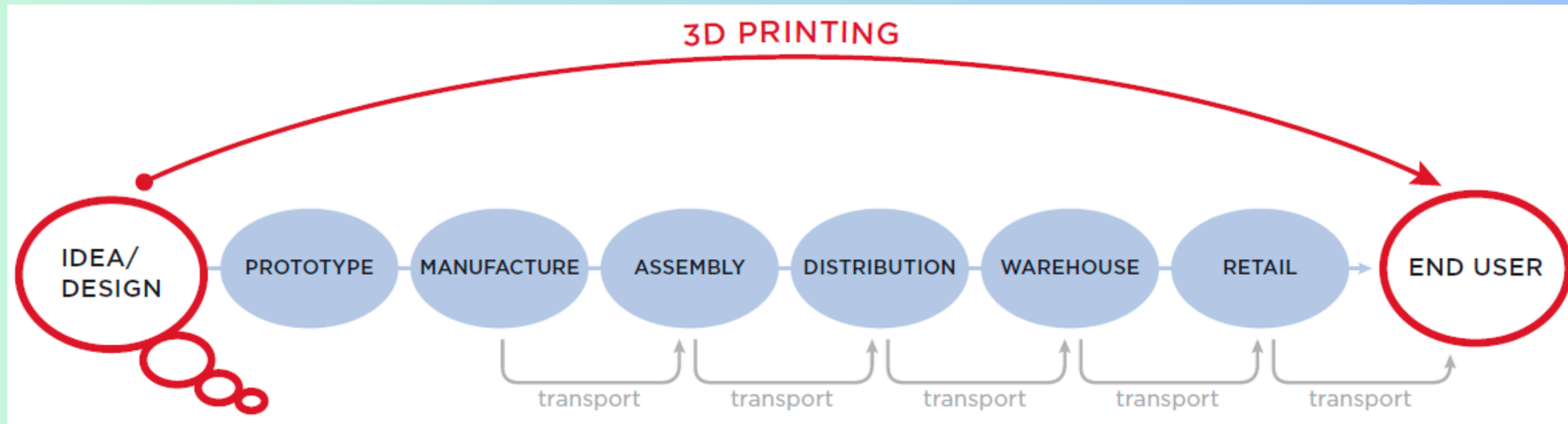


Today manufacturing :

- Today's system is a legacy of Taylorism, Fordism, and Toyotism.
- A model built on mass production and mass consumption.
- It actively leverages globalization.
- While highly efficient for certain products, it is inefficient for others.



Smart manufacturing :

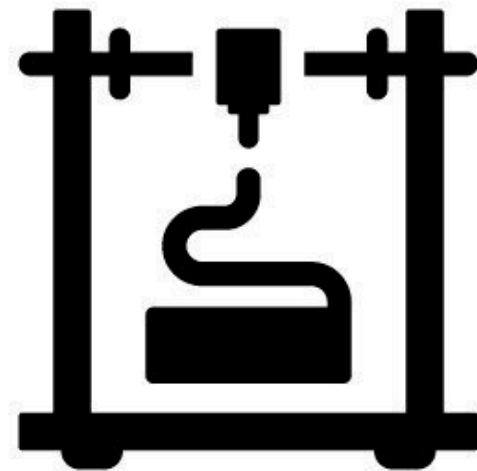


- Instantaneous production
- Localization of the production
- Customization of the production

Domains concerned :



Aerospace



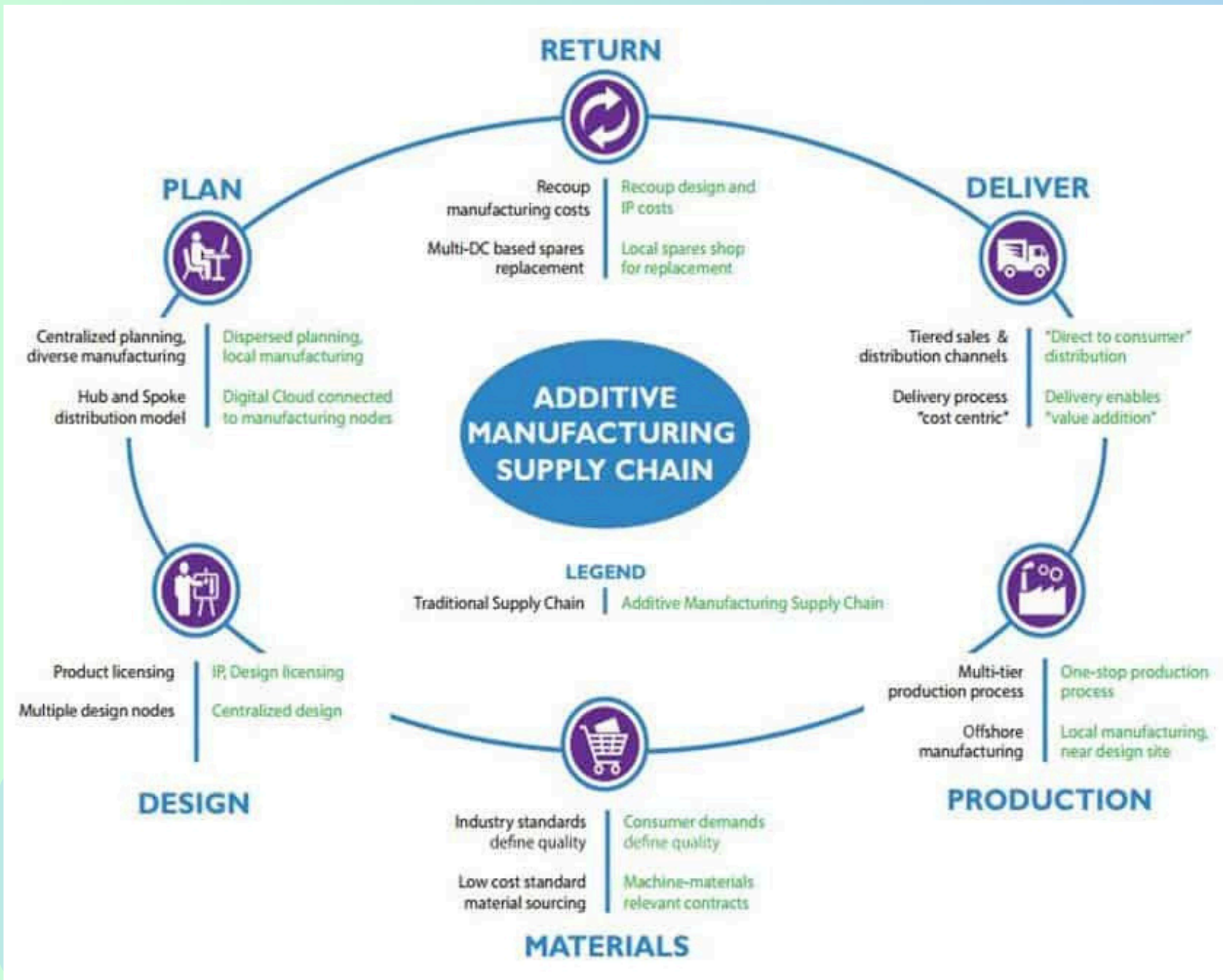
Consumer products



Healthcare

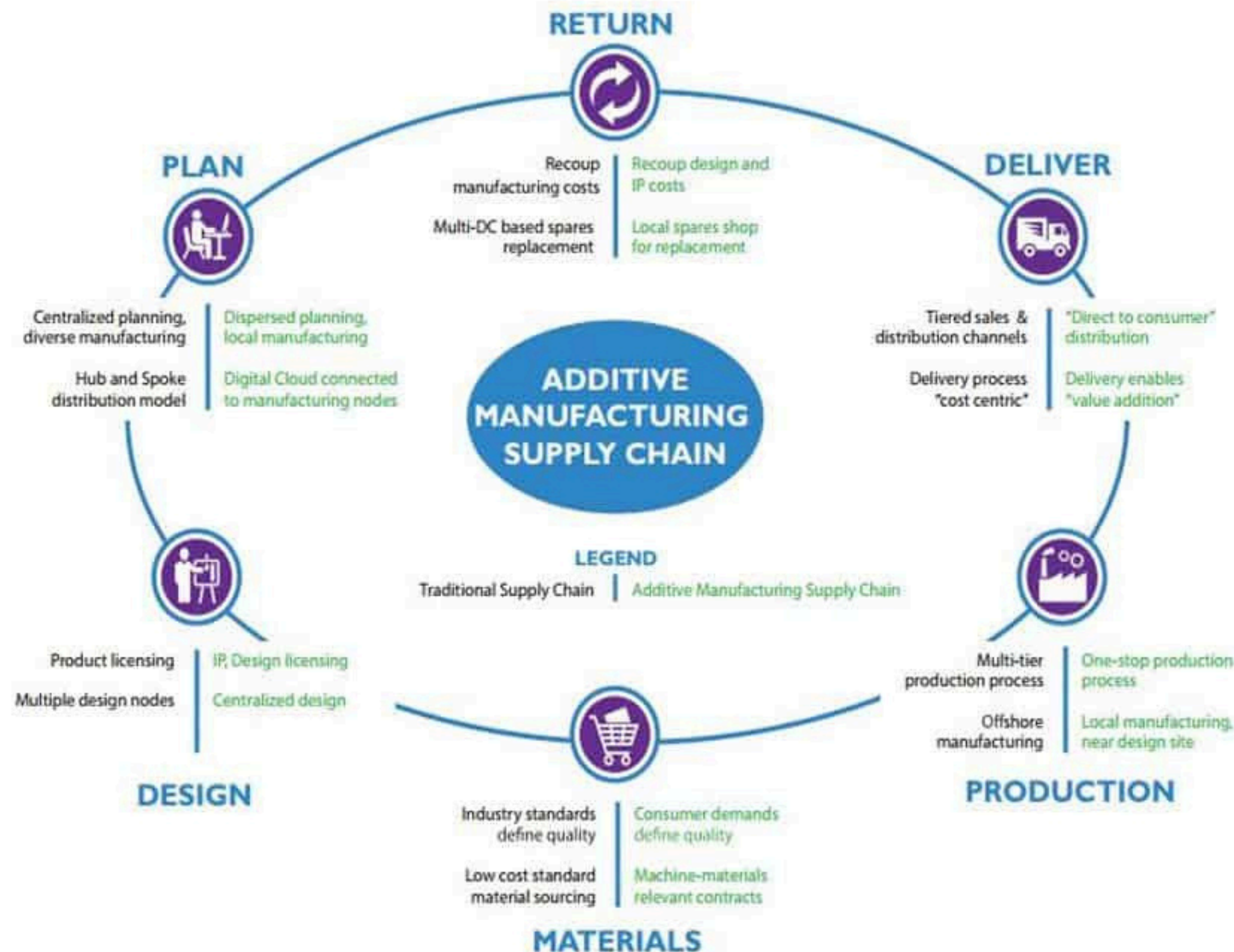
But also other domains such as tooling, spare parts and energy...

AM and supply chain :



- **Planning** : Direct access, universality, accelerate process, no intermediaries
- **Sourcing** : Compact and standard material, one source, brut material
- **Making** : Reduction of cost and time production

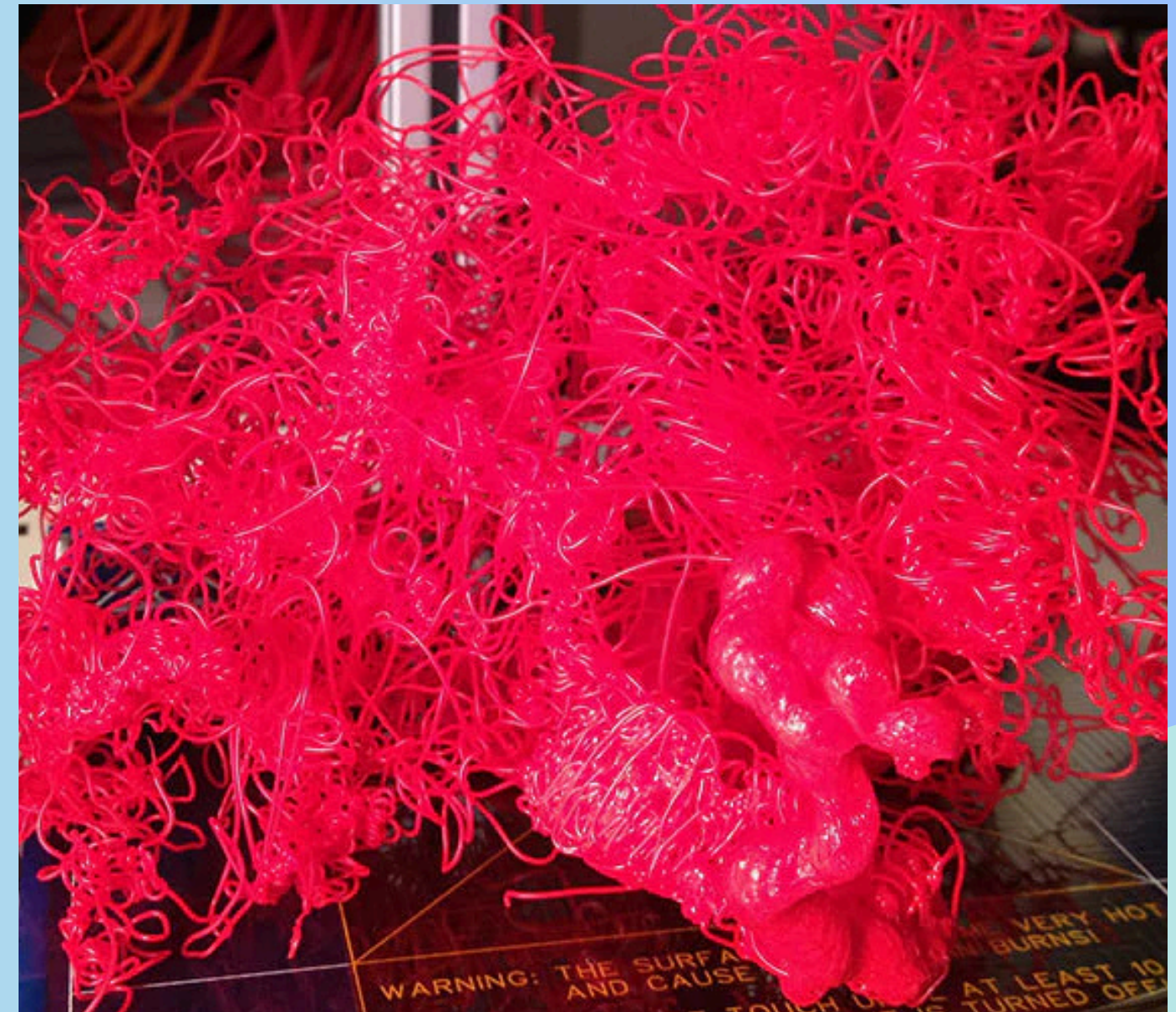
AM and supply chain :



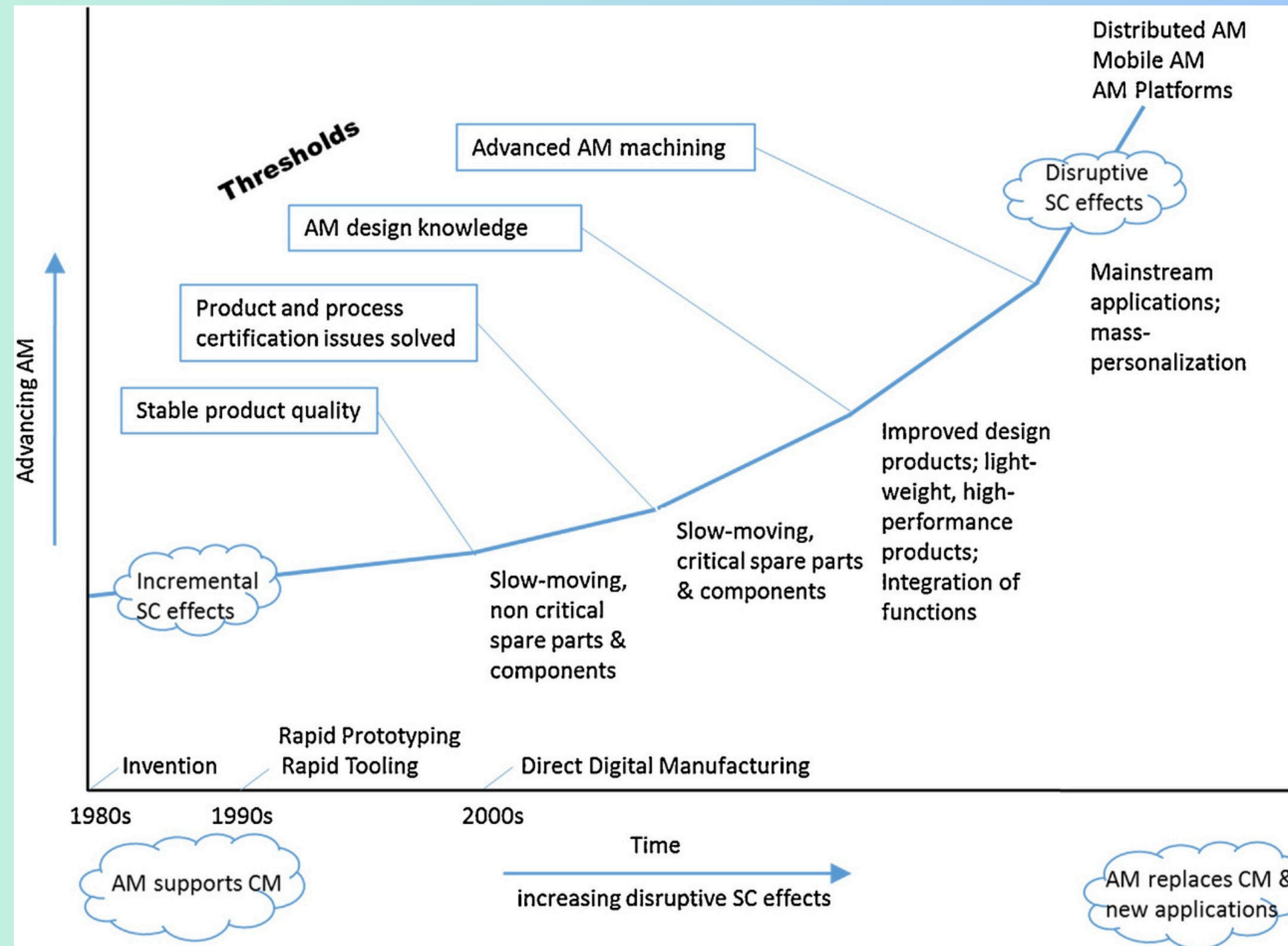
- Delivering : short storage time, low distance of delivering
- Returning : Recycling materials, recycling part, easy to restore and remake

Future challenge of AM in the Industry :

- **Surface finish need to be improved**
- **Technical performance need to be improved**
- **Impossibility of producing some parts**
- **Changement of economic and industrial systems need to be apply**



Future challenge of AM in the Industry :



06

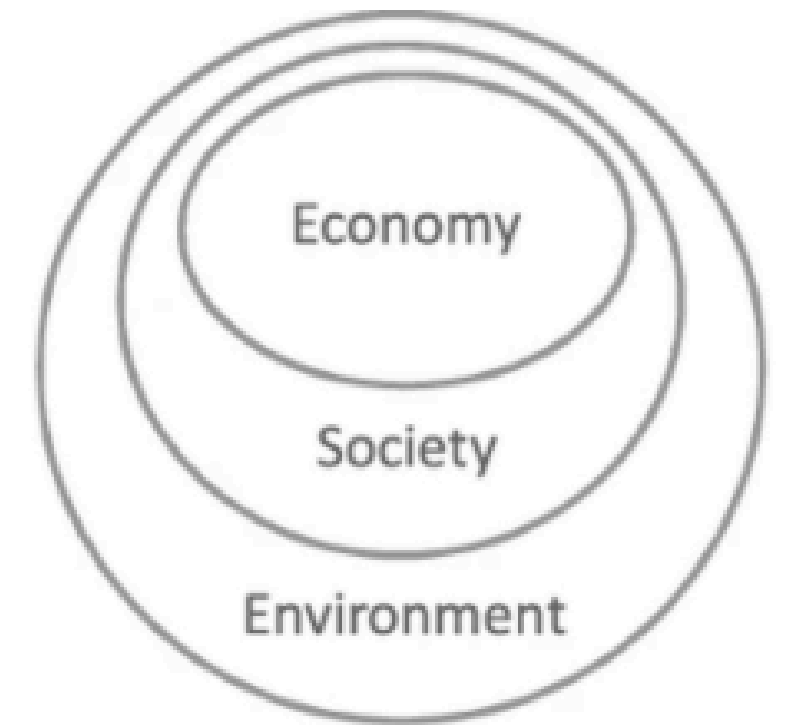
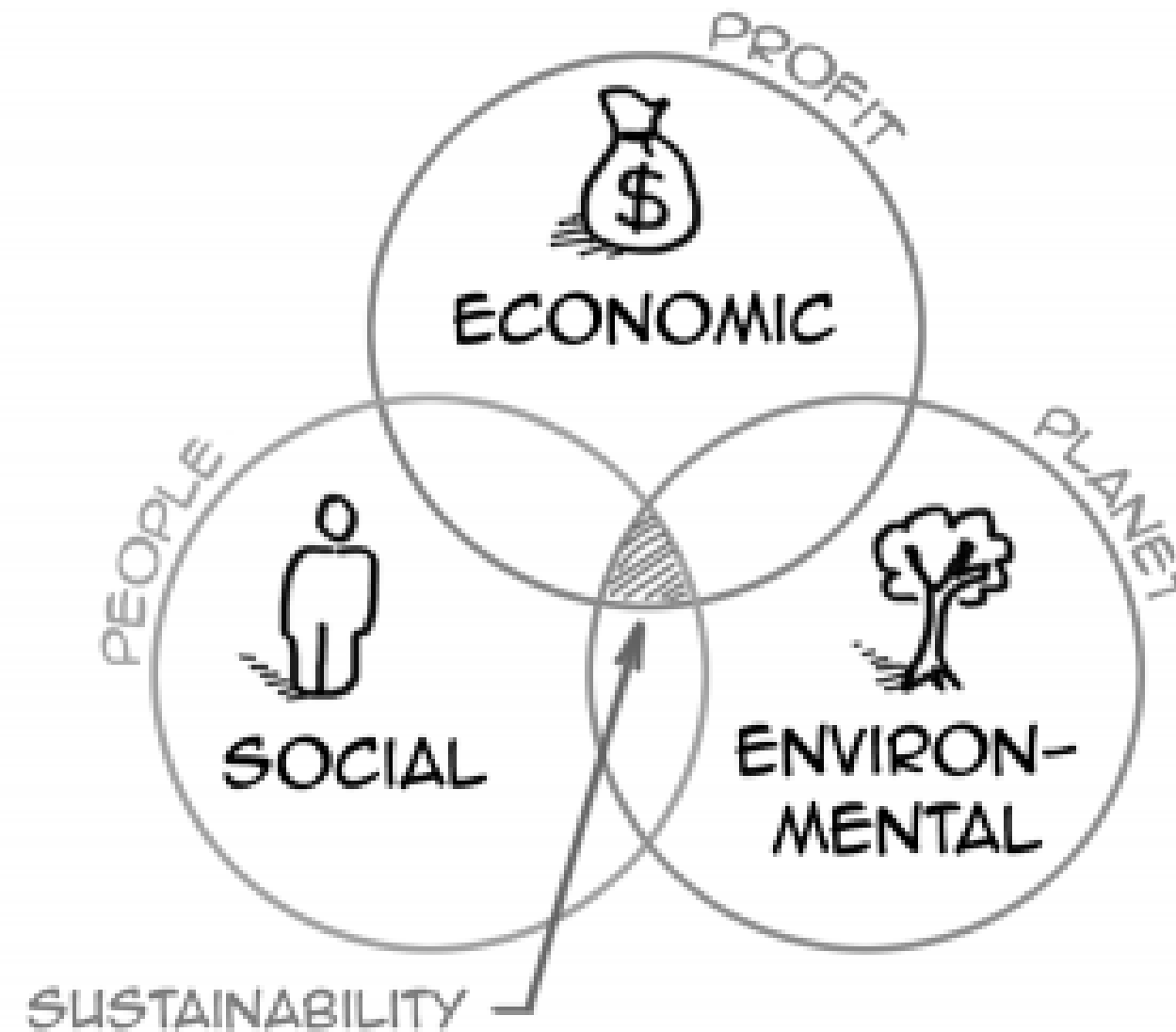
AM for a sustainable future

Signe Hald Lundby - 396856



AM for a sustainable future

The three pillars of sustainability



Benefits

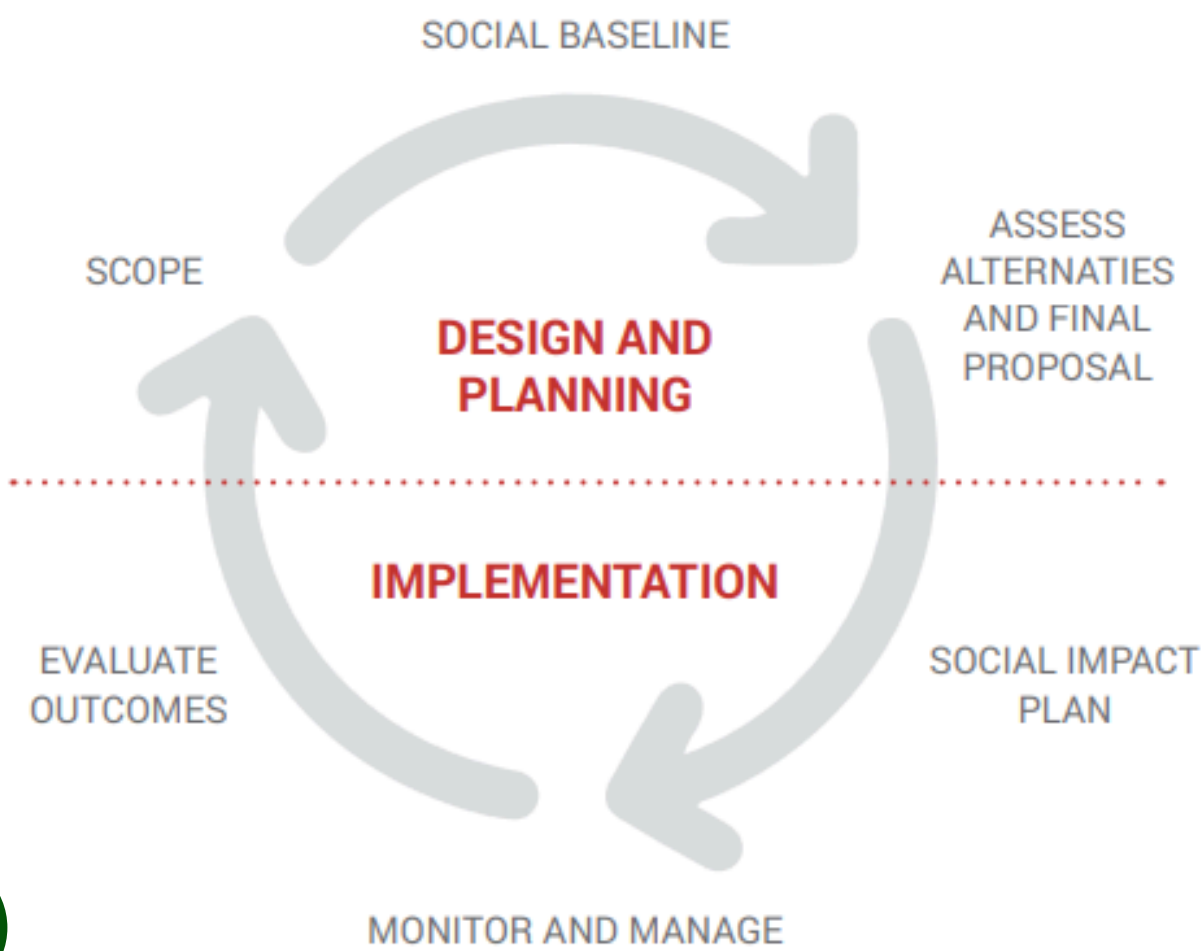


Hot spots

Social Sustainability

Employment, health, and safety

Social sustainability involves a focus on the well-being of people and communities.



Social Impact Assessment

Benefits & opportunities



High demand for skilled labor creates opportunities for upskilling and technical education



Employment growth in software development, material science, and robotics



Use of IoT sensors for real-time monitoring of air quality and exposure levels



Challenges



May displace less-experienced workers



AM risks toxicity and health hazards



Economic Sustainability

Cost-effective production and resource optimization

Economic sustainability ensures long-term well-being by balancing growth, resource efficiency, social fairness, and financial stability.

Benefits & opportunities



Local production reduces transportation needs, lowering logistical costs



Minimizes material waste cost



Enables mass customization at a lower cost than traditional manufacturing



Challenges



High initial investment in AM and I4.0 technologies (equipment, training, and implementation)



Significant barriers without government subsidies or collaborative initiatives.



Scalability to high-volume production is limited due to slow AM processes



Environmental Sustainability

Benefits & opportunities



AM constructs products layer by layer, using only the necessary material



Reduces raw material needs compared to subtractive methods.



Integrating IoT and AI to optimize energy use through real-time monitoring



Enhances accessibility for in-house manufacturing, reducing travel impacts.

Challenges



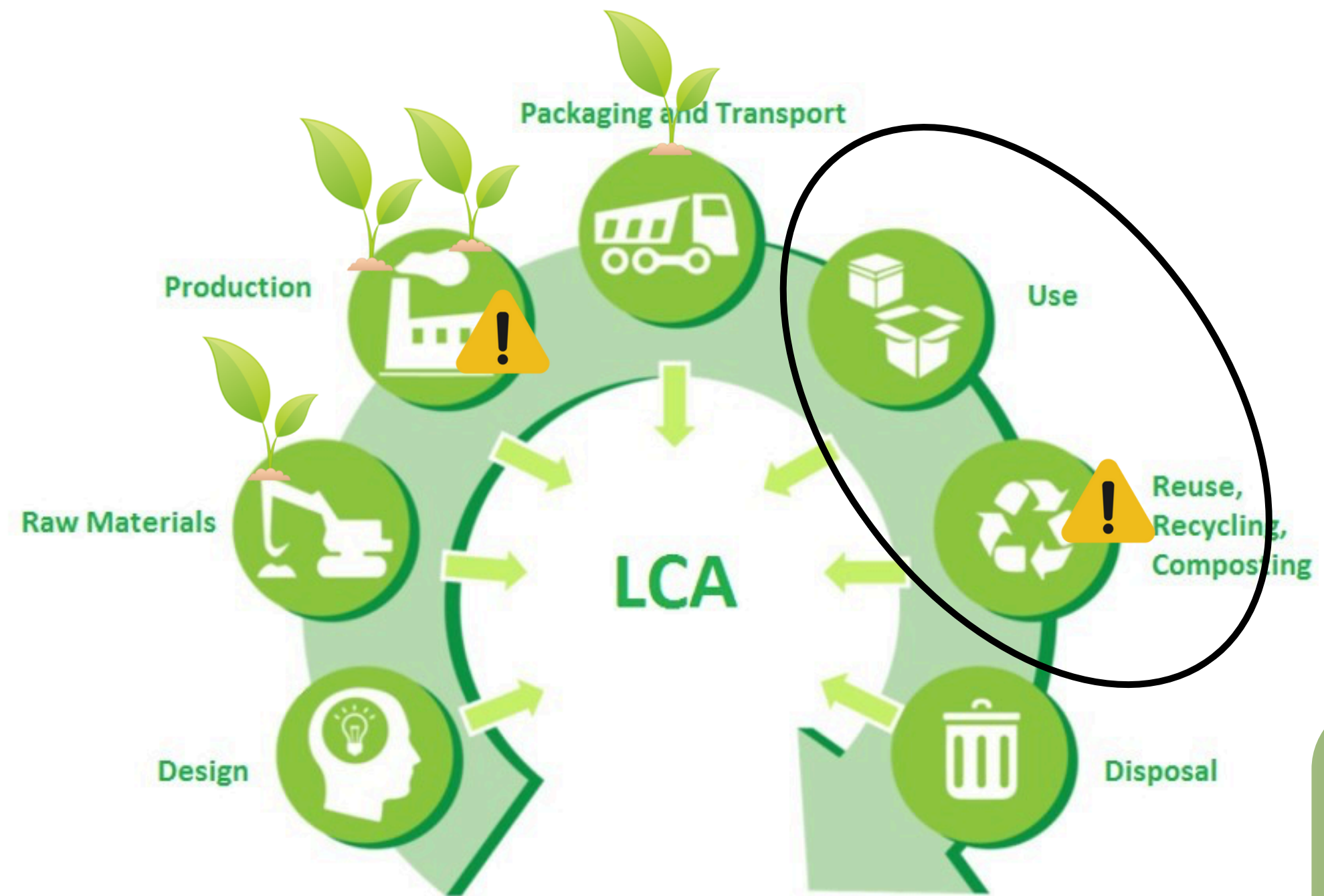
Limited use of recyclable or bio-based materials



AM's energy use can exceed that of conventional methods like injection molding or machining.

- Laser-based AM processes are particularly energy-intensive.

Environmental sustainability ensures the protection of natural resources to meet present needs without compromising future availability



Circular Economy Potential

The Butterfly Diagram

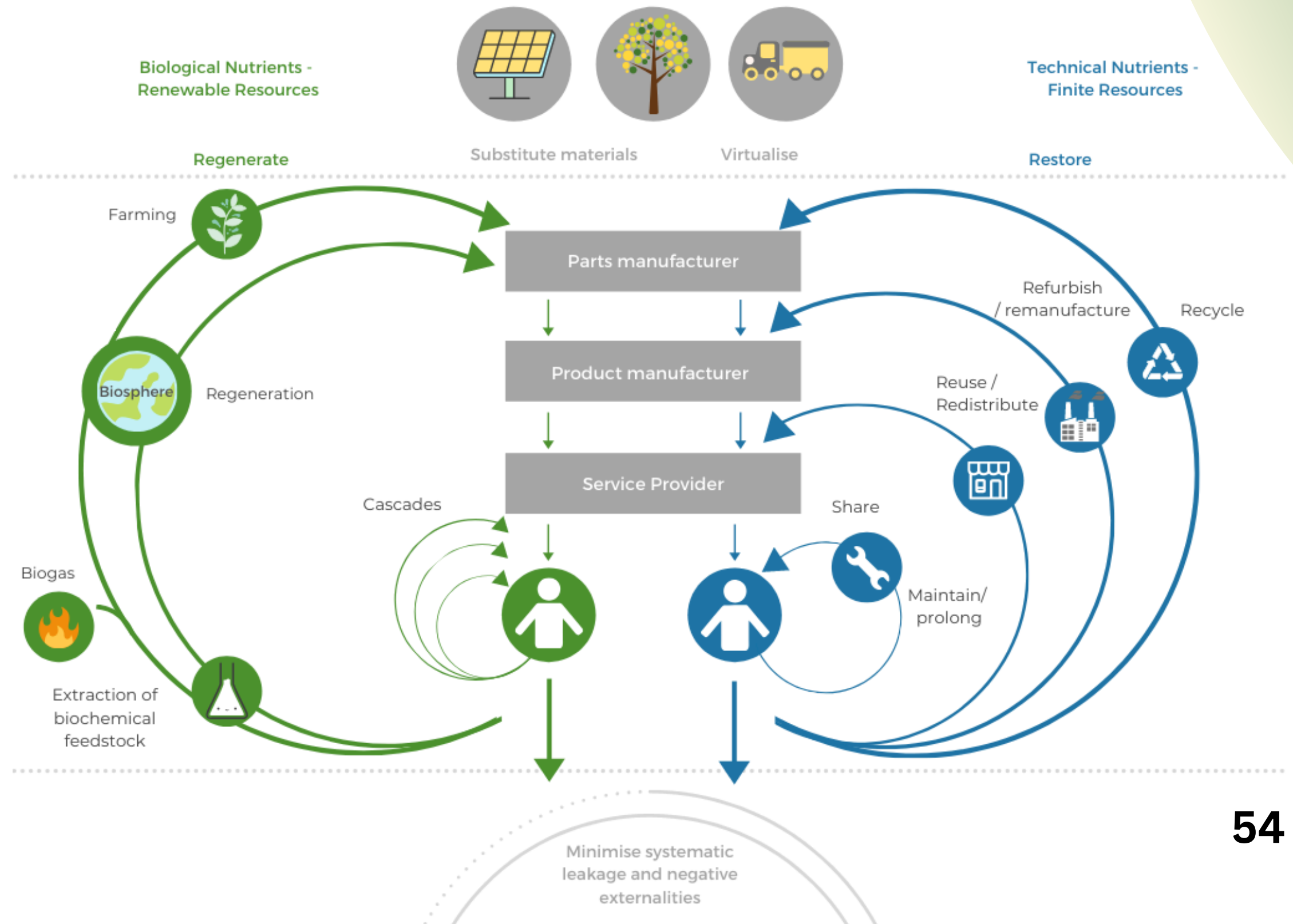
A tool developed by the Ellen MacArthur Foundation that provides a Cradle to Cradle view of the different aspects of Circular Economy needed to facilitate a sustainable transition in practice.

Biological nutrients - Renewable materials

- Capable of decomposing naturally when reaching end of life.
 - E.g. wood, paper, cork, and cotton.

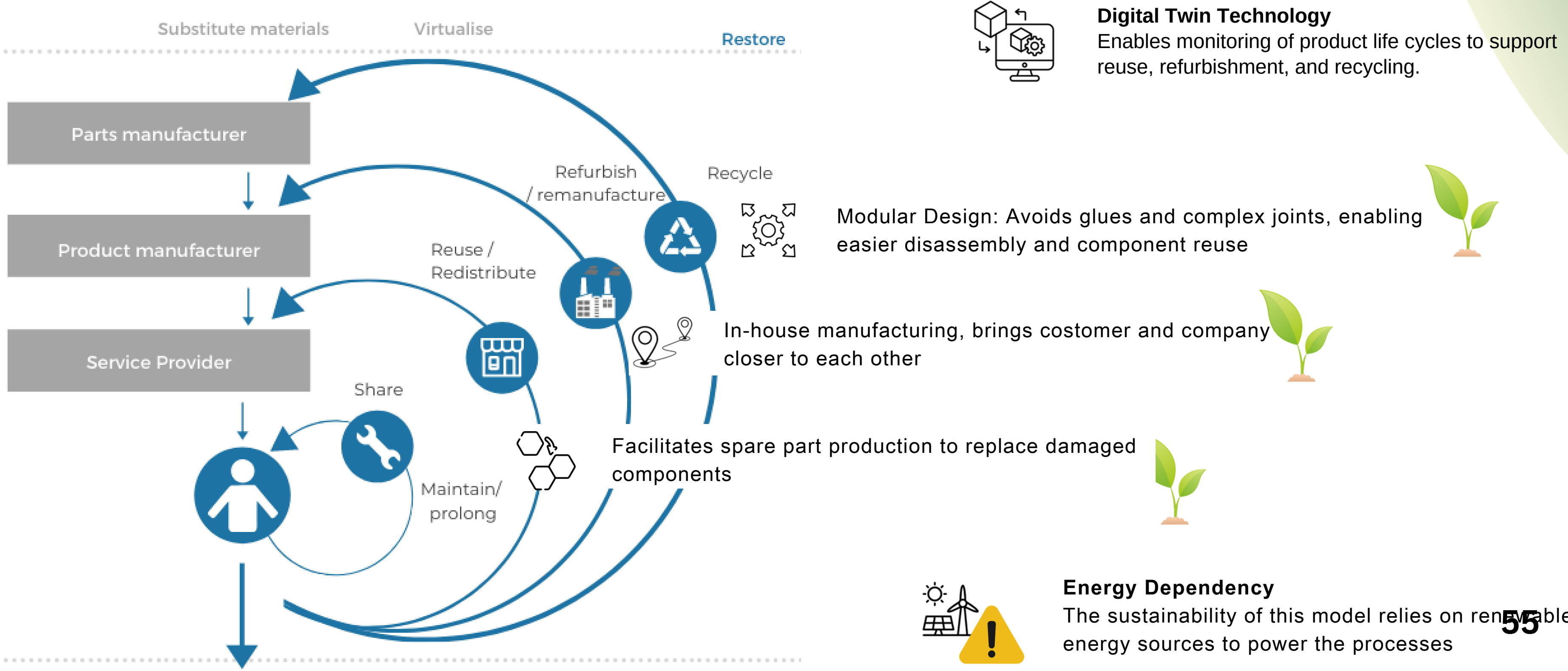
Technical nutrients - Finite materials

- Do not decompose. Therefore, their useful life must be maximized to their full capacity.
 - E.g. aluminum, iron, and plastic



Circular Economy Potential

Extending Product Life Cycles



Sustainable opportunities for AM in I4.0



Energy

Transition to renewable energy sources and integrate IoT and AI for efficiency.



Company Scalability

Provide financial support, shared resources, and training programs to lower adoption barriers



Material

Focus on recyclable and bio-based materials while promoting modular, repairable designs.



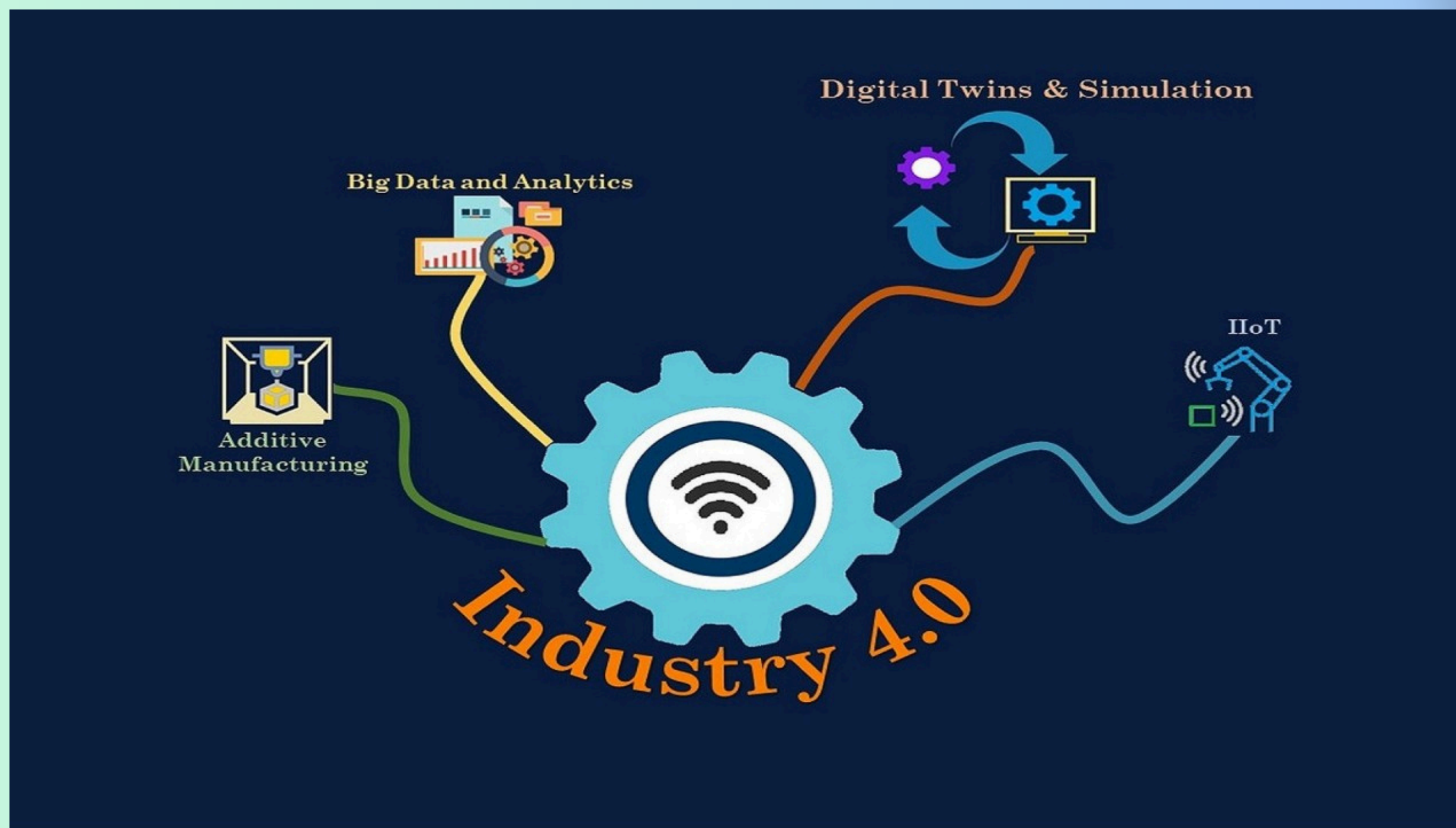
Shared Use

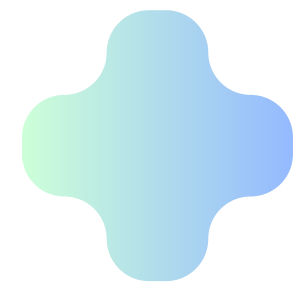
Promote product service systems to maximize product lifespan and reduce unnecessary production.

07

Conclusion

Advantages and challenges





To a new era : Advantage of AM in **Industry 4.0**

- Optimization of production process
- Flexibility and customization
- Localized production
- Environmental benefits
- Competitive advantage for early adopters



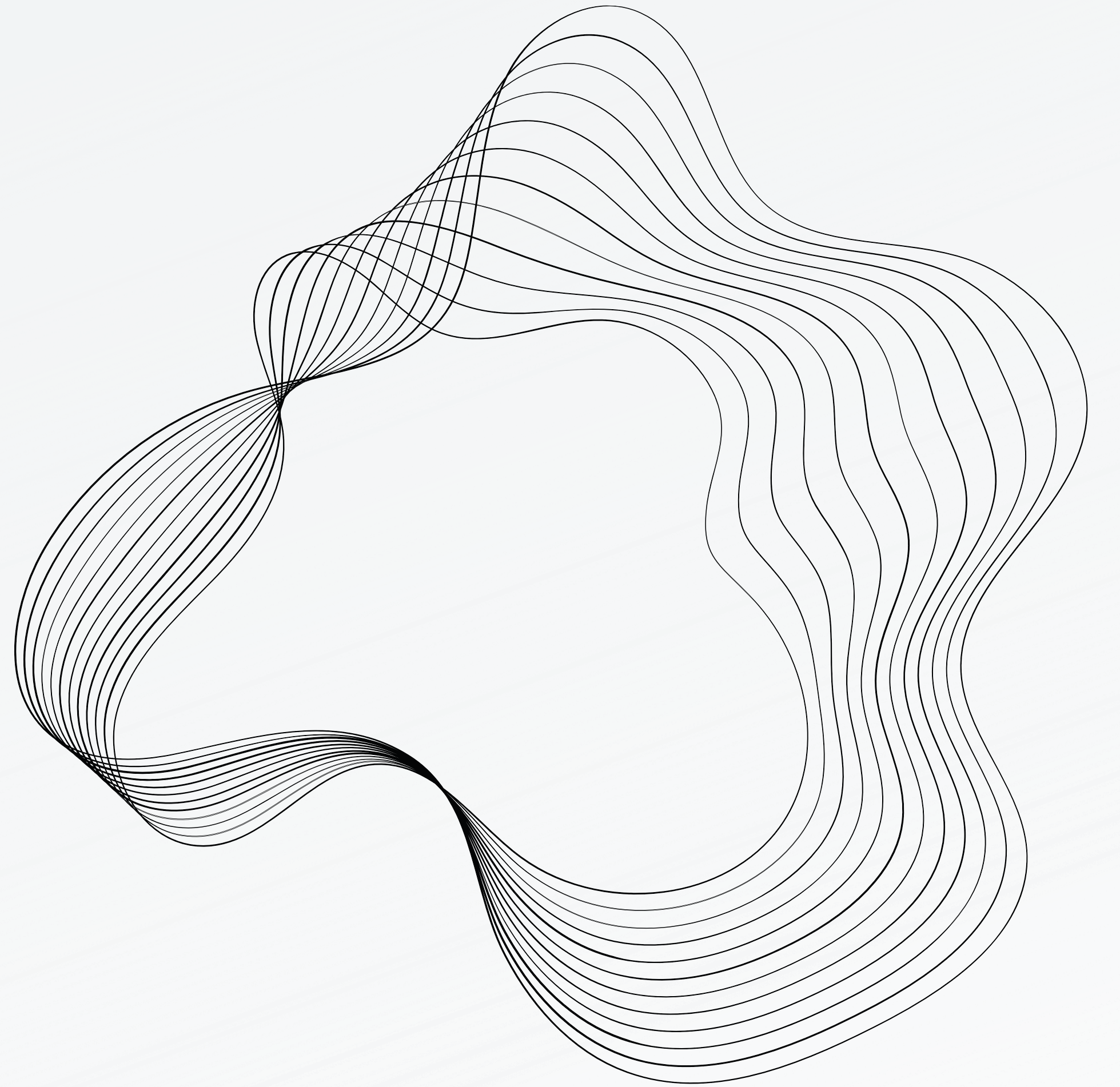


Maybe in a long time...

Challenges of AM in Industry 4.0

- Energy consumption
- Material recyclability
- Inconsistent material properties
- accessibility and adoption
- Integration complexity





THANK YOU!