Innovative Materials For Additive Manufacturing (IMAM)

Proceedings

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Perspectives on the future of additive manufacturing

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Perspectives on the future of additive manufacturing

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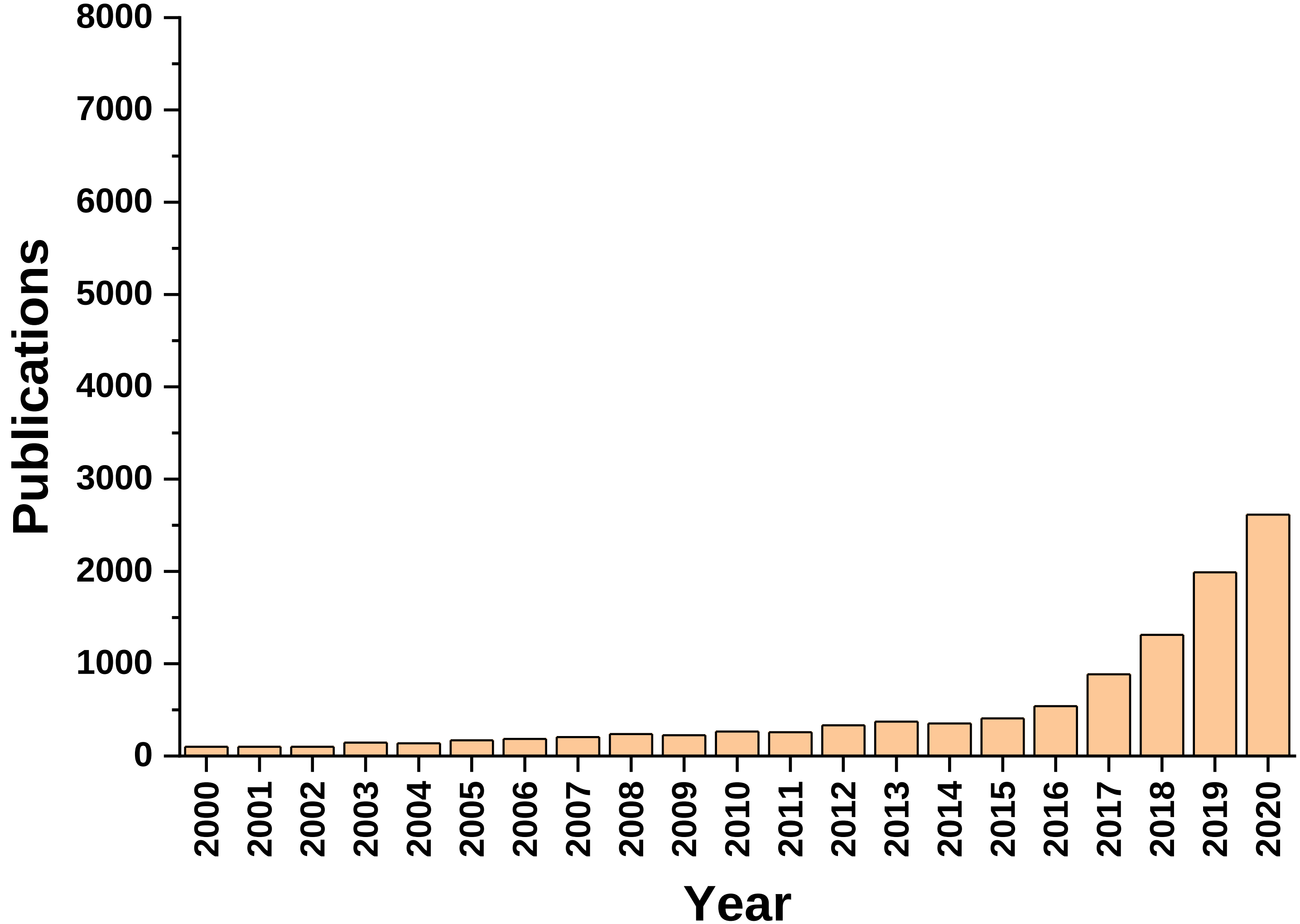
LIST

ADDITIVE MANUFACTURING: WHERE ARE WE?

- From the early days of “rapid prototyping” in the 1980s, there has been a massive increase in the attention paid to AM



From SciFinder search for “additive manufacturing” + “3D printing” + “rapid prototyping” (exact terms)

ADDITIVE MANUFACTURING: WHERE ARE WE?

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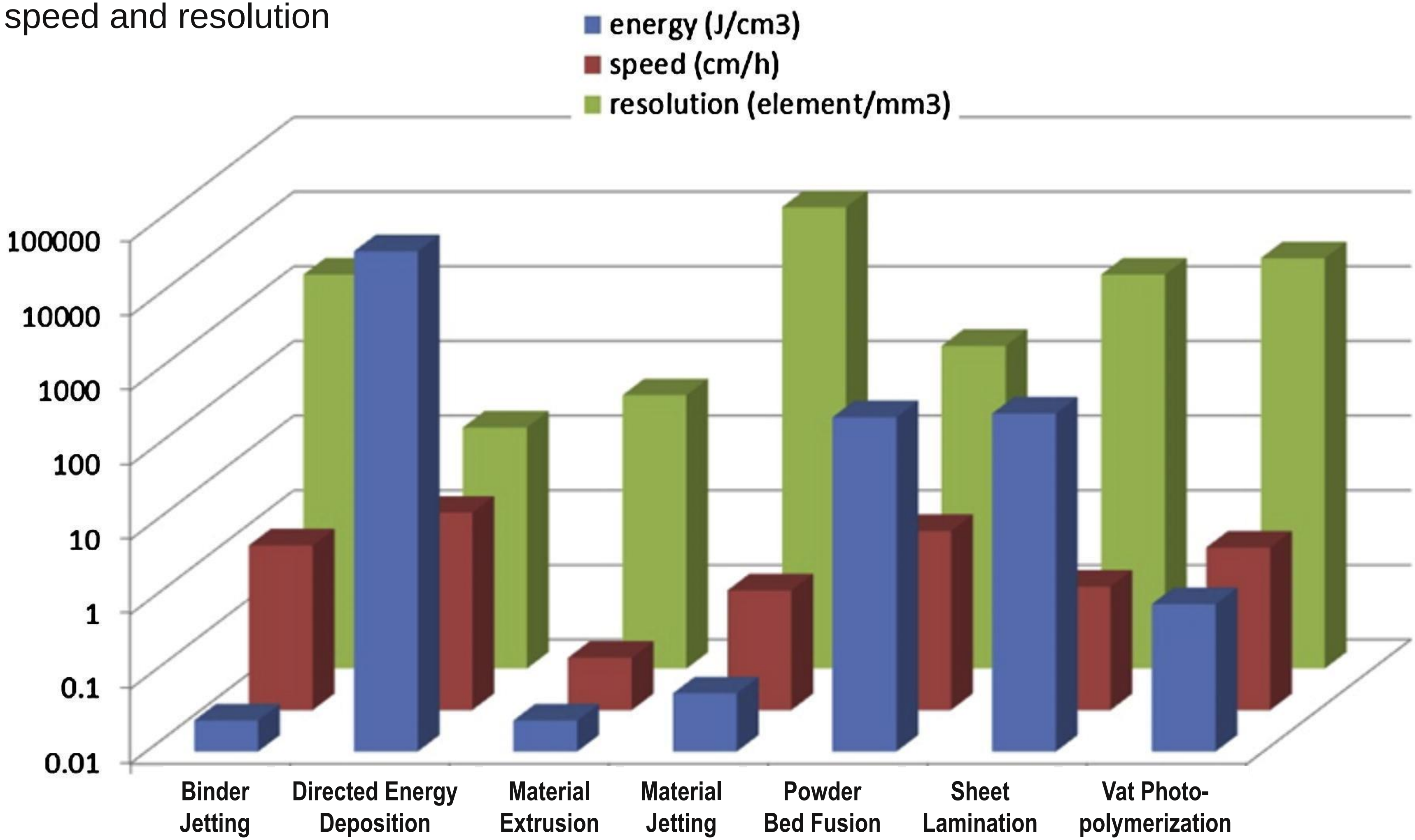
- As a result, AM techniques abound, and may now be applied to a wide range of materials (processes categorized according to ISO/ASTM 52900:2015)

Materials	Example materials	Process categories						
		Vat photo-polymer-ization	Material jetting	Binder jetting	Powder bed fusion	Material extrusion	Directed energy deposition	Sheet lamination
Thermoset Polymers	Epoxies and acrylates	X	X					
Thermo-plastic polymers	Polyamide, ABS, PPSF		X	X	X	X		X
Wood	paper							X
Metals	Steel, Titanium alloys, Cobalt chromium			X	X		X	X
Industrial ceramic materials	Alumina, Zirconia, Silicone nitride	X		X	X			X
Structural ceramic materials	Cement, Foundry sand			X	X	X		
Note: Combinations of the above material classes, e.g. a composite, are possible								

Thompson, M. K.; Moroni, G.; Vaneker, T.; Fadel, G.; Campbell, R. I.; Gibson, I.; Bernard, A.; Schulz, J.; Graf, P.; Ahuja, B.; et al. Design for Additive Manufacturing: Trends, Opportunities, Considerations, and Constraints. *CIRP Annals* **2016**, *65* (2), 737–760.

ADDITIVE MANUFACTURING: WHERE ARE WE?

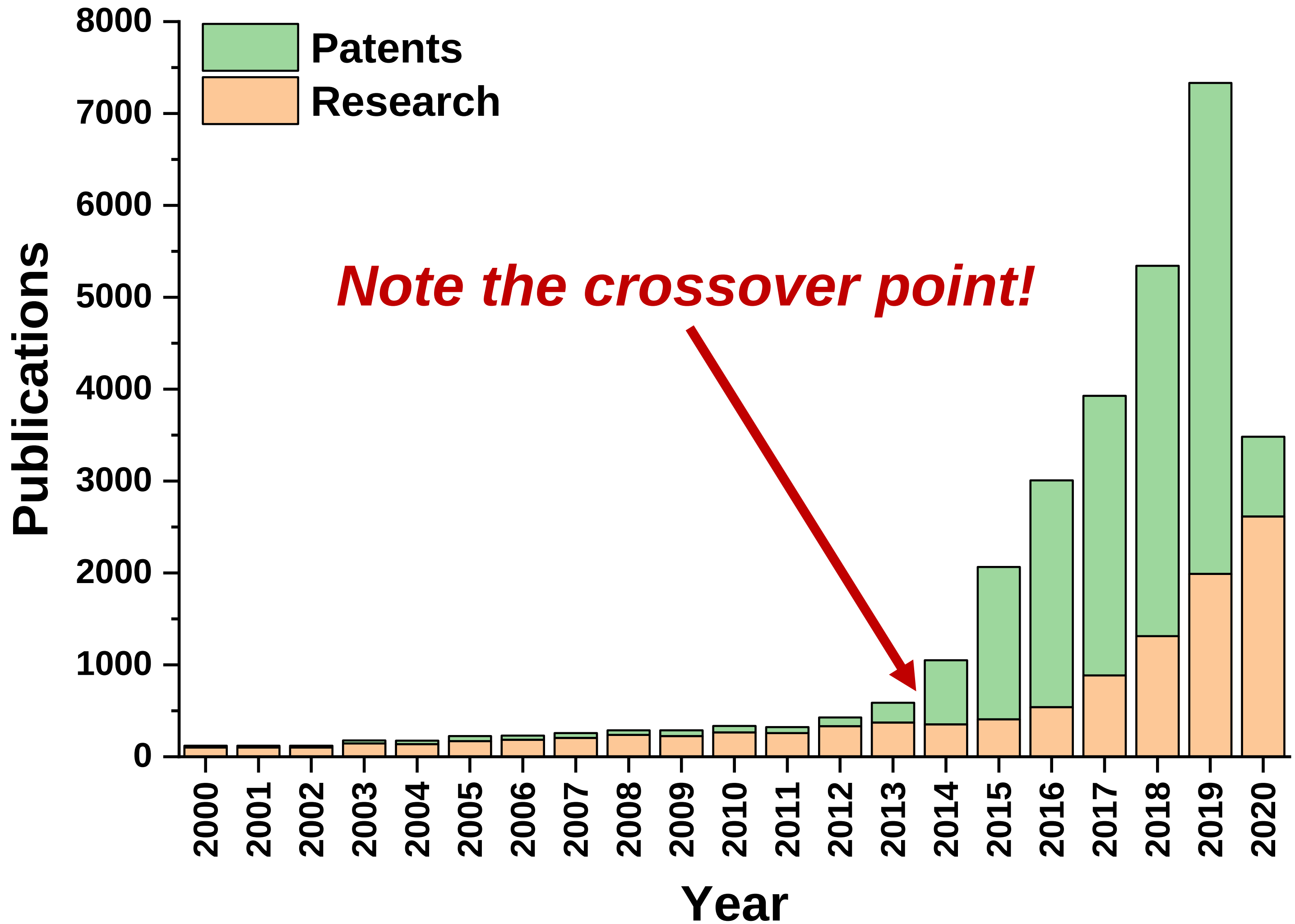
- Needless to say, not all AM technologies are created equal when it comes to energy input, speed and resolution



Tofail, S. A. M.; Koumoulos, E. P.; Bandyopadhyay, A.; Bose, S.; O'Donoghue, L.; Charitidis, C. Additive Manufacturing: Scientific and Technological Challenges, Market Uptake and Opportunities. *Materials Today* **2018**, *21* (1), 22–37.

ADDITIVE MANUFACTURING: WHERE ARE WE?

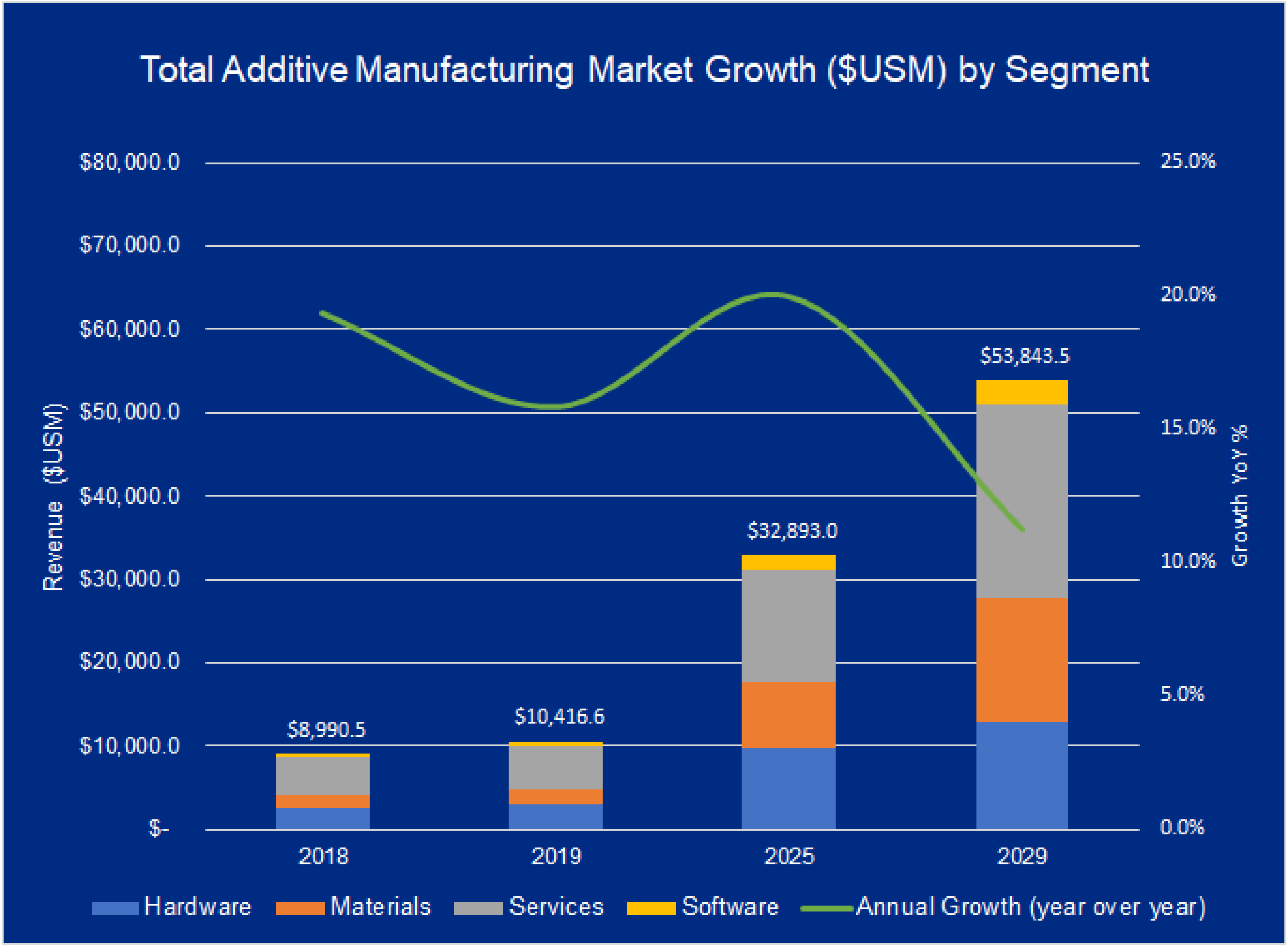
- Industrial implementation has followed research activity and is now growing at an extremely rapid pace



From SciFinder search for “additive manufacturing” + “3D printing” + “rapid prototyping” (exact terms)

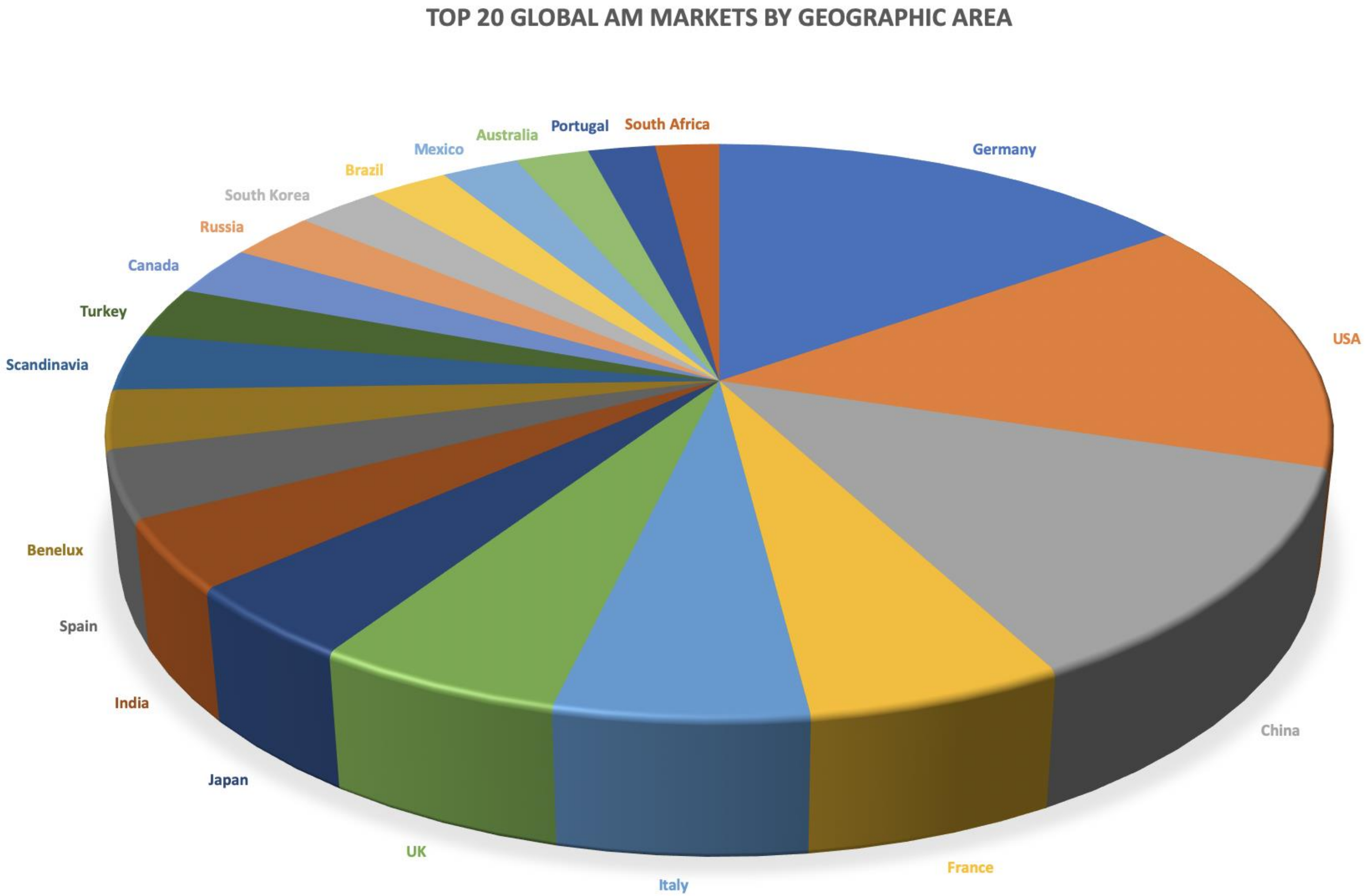
ADDITIVE MANUFACTURING: WHERE ARE WE?

- This is reflected in the state of the AM market, with large growth predicted
- For context, global manufacturing market is ~$12T – so **AM is only ~0.1%(!)**



https://www.makepartsfast.com/2019-additive-manufacturing-market-growth-surpassed-10b-worldwide/

ADDITIVE MANUFACTURING: WHERE ARE WE?



Germany, the USA and China are currently the top three AM markets worldwide

https://www.3dprintingmedia.network/the-top-20-global-am-markets/

ADDITIVE MANUFACTURING: WHERE ARE WE?

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- A recent survey of the industrial 3D printing landscape identifies nearly 200 organizations

[The Additive Manufacturing Landscape 2019](#) [Whitepaper]. *AMFG*.

ADDITIVE MANUFACTURING: WHERE ARE WE?

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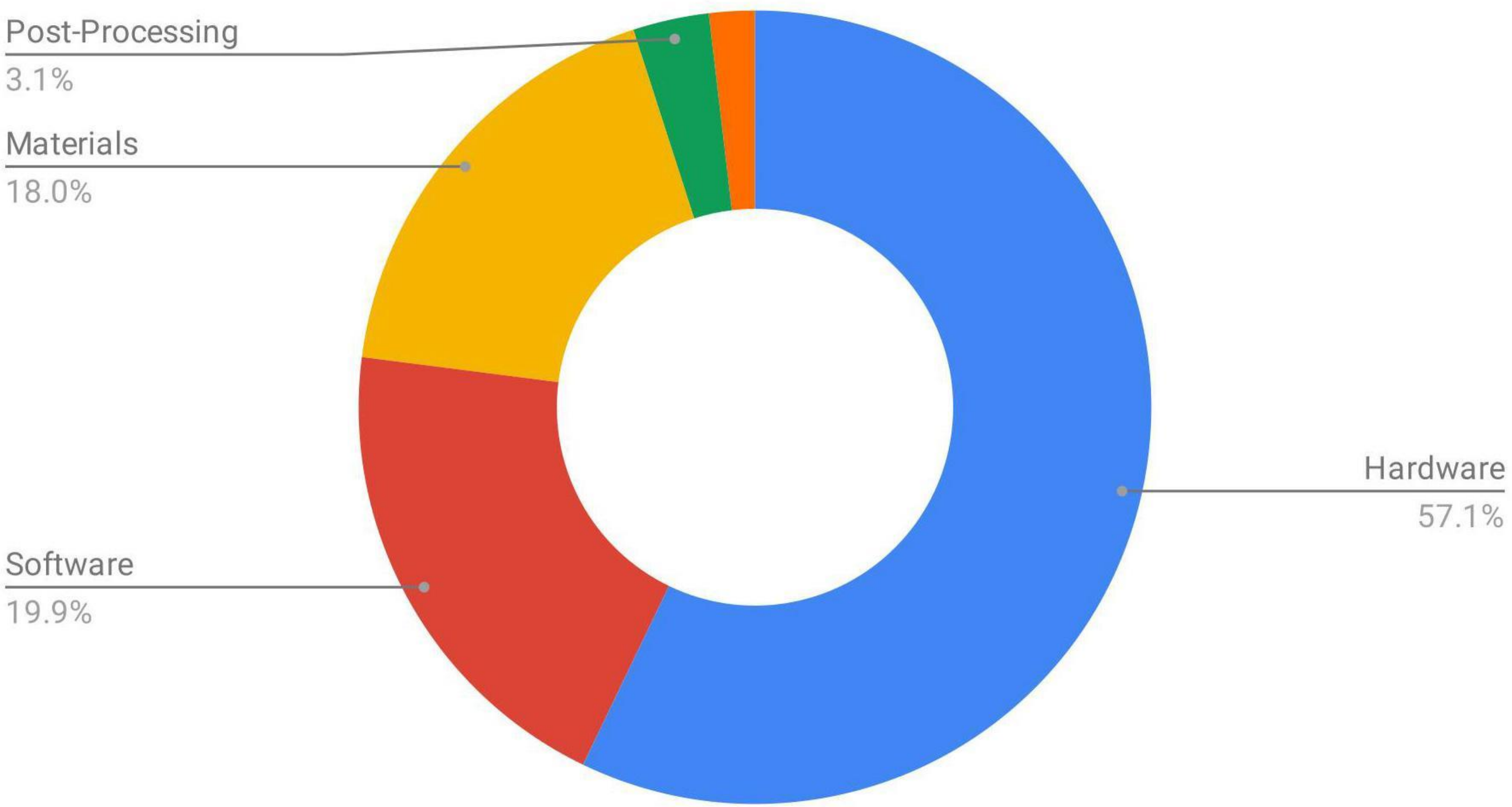
- Most of these organizations are focused on hardware (that is, AM equipment)



The Additive Manufacturing Landscape 2019 [Whitepaper]. *AMFG*.

ADDITIVE MANUFACTURING: WHERE ARE WE?

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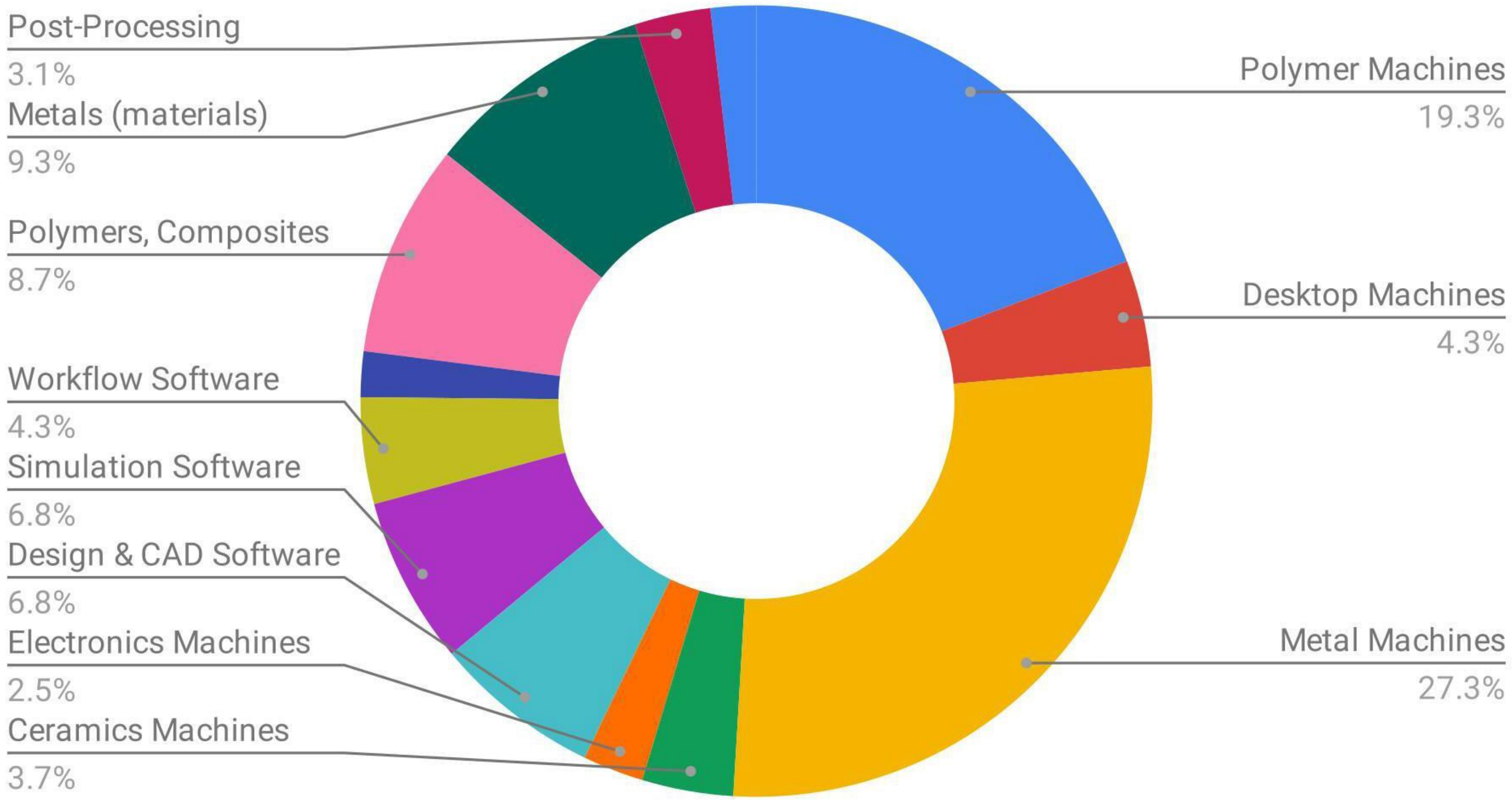
- Further breaking things down, machines for metal and polymer AM dominate



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ADDITIVE MANUFACTURING: WHERE ARE WE?

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- As of April 2019, three 3D printing companies have reached **unicorn status** (meaning they have a valuation of over $1 billion; 326 companies worldwide had such status at that time)
- All are **hardware manufacturers** (two polymer-focused, one metal-focused)

Carbon	**$1.7B**
Desktop Metal	**$1.5B**
formlabs	**$1.06B**

The Additive Manufacturing Landscape 2019 [Whitepaper]. *AMFG*.

ADDITIVE MANUFACTURING: WHERE ARE WE?

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- Overall trends
  - Competition is increasing among metal 3D printers
  - Polymer 3D printing continues to mature
  - Software and automation are becoming increasingly important
  - Many collaborations, partnerships and acquisitions

- Materials trends
  - Polymers were the largest AM materials market segment in terms of revenue ($5.5B polymer AM revenue in 2018)
  - Increasing focus on high performance polymers
  - Metal AM materials market saw strong growth five years running (42% in 2018)
  - Metal AM is particularly attractive when using metals that are costly to process via conventional methods (titanium for example)

The Additive Manufacturing Landscape 2019 [Whitepaper]. *AMFG*.

ADDITIVE MANUFACTURING: WHERE ARE WE?

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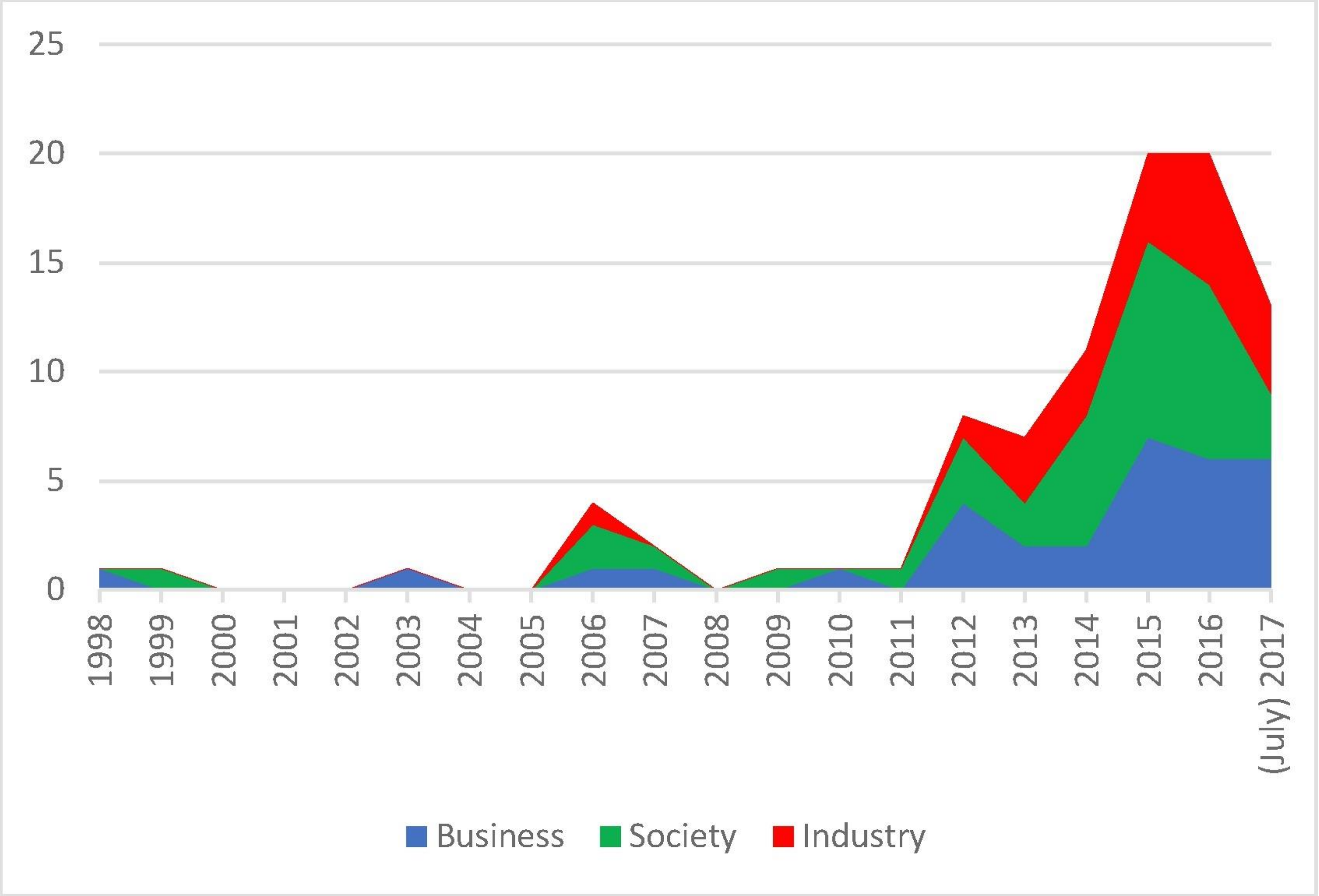
- This has resulted in a growing body of interdisciplinary research focused on the **impact** of AM as well



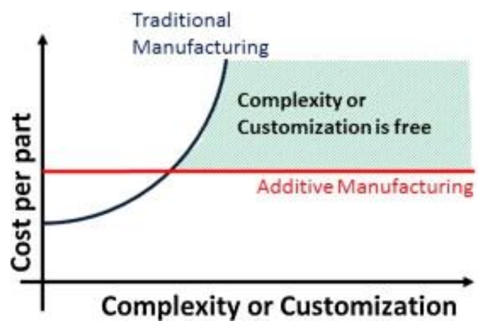
Caviggioli, F.; Ughetto, E. A Bibliometric Analysis of the Research Dealing with the Impact of Additive Manufacturing on Industry, Business and Society. *International Journal of Production Economics* **2019**, *208*, 254–268.

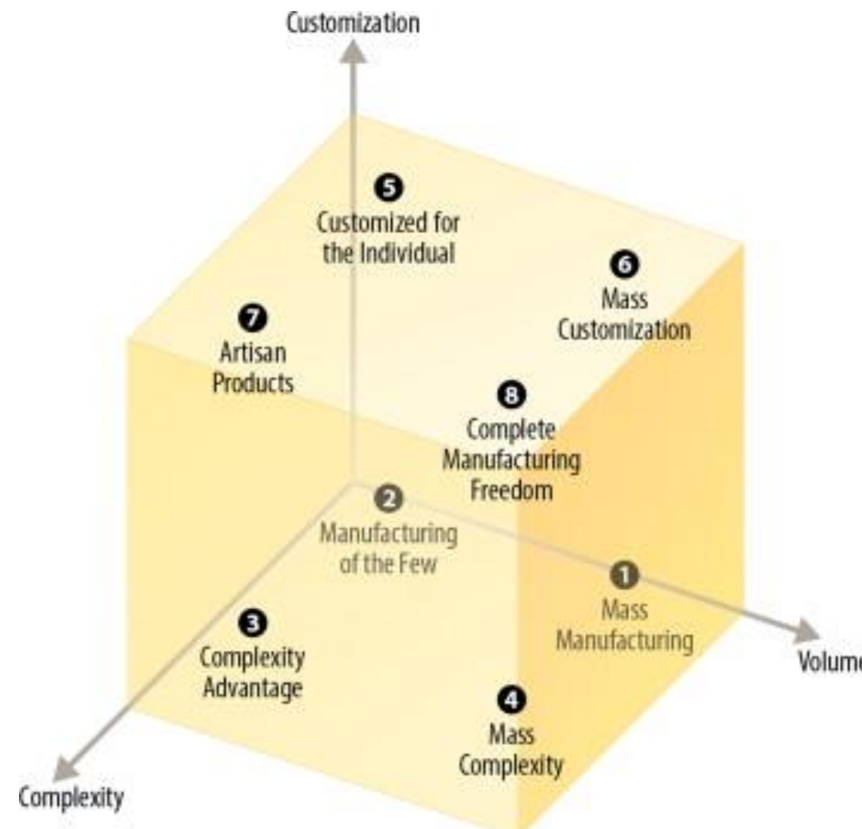
ADDITIVE MANUFACTURING: WHERE ARE WE HEADED?

- Considering the future of AM and its impact on business and industry, one obvious question to ask is “where will AM make sense to use”?

- This has been studied, and can be addressed by considering three factors:
  - Part complexity
  - The need for customization
  - Anticipated production volumes

- Regions 3-8 are most promising





- AM is competitive in region 2 only if costs / lead times are lower
- AM provides agility, so better to work in multiple regions

Conner, B. P.; Manogharan, G. P.; Martof, A. N.; Rodomsky, L. M.; Rodomsky, C. M.; Jordan, D. C.; Limperos, J. W. Making Sense of 3-D Printing: Creating a Map of Additive Manufacturing Products and Services. *Additive Manufacturing* **2014**, *1–4*, 64–76.

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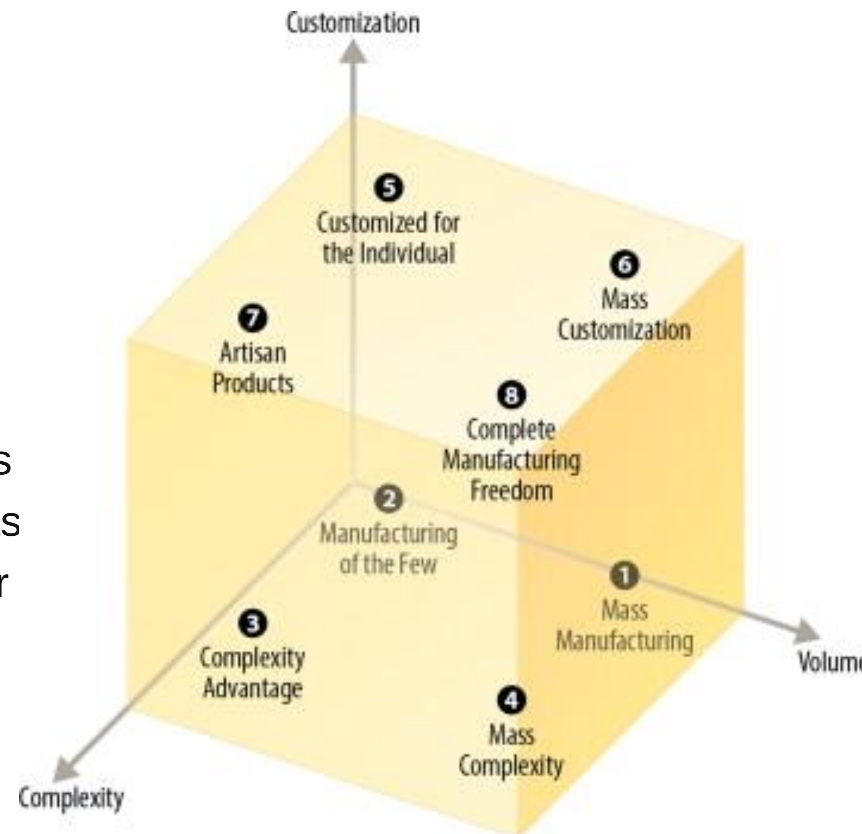

Examples

- Region 1: Automotive panels
- Region 2: (where AM started)
- Region 3: Aerospace assemblies
- Region 4: Ti cups for hip implants
- Region 5: Personalization, repair
- Region 6: Invisalign® braces
- Region 7: Art, prosthetics, race car components
- Region 8: (the future?)

Conner, B. P.; Manogharan, G. P.; Martof, A. N.; Rodomsky, L. M.; Rodomsky, C. M.; Jordan, D. C.; Limperos, J. W. Making Sense of 3-D Printing: Creating a Map of Additive Manufacturing Products and Services. *Additive Manufacturing* **2014**, *1–4*, 64–76.

ADDITIVE MANUFACTURING: WHERE ARE WE HEADED?

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- Having covered a range of applications, the second question relates to the effects of the development and implementation of increasingly advanced AM

- This has been studied as well:

Technological Forecasting & Social Change 117 (2017) 84–97

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

ELSEVIER

Predicting the future of additive manufacturing: A Delphi study on economic and societal implications of 3D printing for 2030

Ruth Jiang [a,*], Robin Kleer [a,b], Frank T. Piller [a]

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[b] Technical University of Berlin, Chair of Technology and Innovation Management, Straße des 17. Juni 135, 10623 Berlin, Germany

- The Delphi method is an interactive multi-stage forecasting method relying on experts to identify technical developments and trends
- The "Real-Time Delphi" method used in this work improves on the original (developed by the RAND Corporation in the 1950s-60s for strategic planning)
- Here, 65 experts → 3510 quantitative estimates, 1172 qualitative comments
- From these results a "most probable" scenario for AM in 2030 was developed

ADDITIVE MANUFACTURING: WHERE ARE WE HEADED?

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Most probable scenario developed for AM in 2030

- Considering 18 projections evaluated across four categories
  - Production, supply chain, and localization (6)
  - Business models and competition (4)
  - Consumer and market trends (5)
  - Intellectual property (IP) and policy (3)
- Most probable future based on projections evaluated by the expert panel with the highest probability of occurrence in 2030 and sufficient consensus between the expert evaluations
- We can think of these as educated guesses – or as indicators of what it is expected that the field should deliver
- Taken in this way, there are clear RD&I implications associated with each proposition / the relevant conclusion (some supplementary thoughts are provided here)

Jiang, R.; Kleer, R.; Piller, F. T. Predicting the Future of Additive Manufacturing: A Delphi Study on Economic and Societal Implications of 3D Printing for 2030. *Technological Forecasting and Social Change* **2017**, *117*, 84–97.

ADDITIVE MANUFACTURING: WHERE ARE WE HEADED?

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Most probable scenario for AM in 2030: Product Development

Proposition: In 2030, conventional measures of "time to market", "product life cycle" and "ramp-up" will have diminished as digital products are in continuous beta stage and are subjected to frequent design iterations and constant modifications.

Conclusion: In 2030, design and manufacturing of consumer products and less-critical industrial products will not be subject of conventional performance measures any longer as they will be modified in frequent iterations.

Top high-probability argument: Physical products will increasingly become like software-based services or apps. This development is especially likely in industries where design and style play an important role.

Implications (DS): Need agile systems, ways to reuse obsolete parts

Jiang, R.; Kleer, R.; Piller, F. T. Predicting the Future of Additive Manufacturing: A Delphi Study on Economic and Societal Implications of 3D Printing for 2030. *Technological Forecasting and Social Change* **2017**, *117*, 84–97.

ADDITIVE MANUFACTURING: WHERE ARE WE HEADED?

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Most probable scenario for AM in 2030: Product Attributes

Proposition: In 2030, manufacturing of spare parts will be divided into two systems: less critical parts will be produced locally via additive manufacturing, whereas critical parts will be made at specialist hubs with specific qualification/quality control skills, primarily using conventional manufacturing techniques.

Conclusion: In 2030, all (critical as well as non-critical) spare parts will be produced with additive manufacturing.

Top high-probability argument: There will be a trend towards local production of spare parts with additive manufacturing due to time- and moneysaving options (on-demand availability, logistics).

Implications (DS): Consistently high part quality will be essential here; still room to improve, especially with regard to polymers, in order to match bulk properties; keep an eye on fatigue!

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ADDITIVE MANUFACTURING: WHERE ARE WE HEADED?

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Most probable scenario for AM in 2030: Product Attributes

Proposition: In 2030, a significant amount of additive manufacturing-produced products will consist of multi-materials and/or contain embedded electronics, enabling a broad range of applications.

Conclusion: In 2030, there will be multi-material products as industries and users pursue these strongly.

Top high-probability argument: This is what additive manufacturing is capable of and meant for and an inevitable development.

Implications (DS): Need to be able to integrate multiple classes of materials into AM-produced assemblies in a consistent, high quality fashion; must also address disassembly / reuse / recycling of such assemblies now, before unintentionally creating the next environmental crisis – “complexity is free” only addresses manufacture, not end-of-life

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ADDITIVE MANUFACTURING: WHERE ARE WE HEADED?

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Most probable scenario for AM in 2030: Channels of Distribution

Proposition: In 2030, a significant number of consumers will utilize online databases (repositories) to purchase product designs or to freely access open-source designs for additive manufacturing printing purposes.

Conclusion: In 2030, enthusiasts, tinkerers, and new consumer generations will utilize additive manufacturing and use online databases to purchase designs due to broad availability of printers in job shops etc.

Top high-probability argument: This is already emerging and people already do this. With broad access to either consumer 3D printers or additive manufacturing services, the number will increase even more.

Implications (DS): Critical need for AM-oriented design tools, incl. design for end-of-life (plus hardware and materials to realize designs)

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ADDITIVE MANUFACTURING: WHERE ARE WE HEADED?

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Most probable scenario for AM in 2030: Channels of Distribution

Proposition: In 2030, an important regulatory measure will be the regulation of additive manufacturing file-sharing platforms.

Conclusion: In 2030, governments will try to regulate file sharing platforms, but will not be effective in doing so. Firms will have to look for new sources of competitive advantage.

Top high-probability argument: If businesses should grow around additive manufacturing, there needs to be some sort of protection for design platforms.

Implications (DS): Individual designs will matter far less than the ability to generate such designs (AM-oriented design tools) and then realize them in practice (AM systems and compatible materials)

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ADDITIVE MANUFACTURING: WHERE ARE WE HEADED?

Most probable scenario for AM in 2030: After Market

Proposition: In 2030, the difficulty of defending conventional intellectual property for digital products will lead to a significantly larger use of novel forms of intellectual property like Creative Commons, open source.

Conclusion: In 2030, other forms of intellectual property will be necessary in order for additive manufacturing to be adopted in industries.

Top high-probability argument: The adoption of additive manufacturing requires non-conventional intellectual property. It is a necessary enabler for the digital manufacturing community and will move in the same direction as the music and film industry.

Implications (DS): …more lawyers?

Jiang, R.; Kleer, R.; Piller, F. T. Predicting the Future of Additive Manufacturing: A Delphi Study on Economic and Societal Implications of 3D Printing for 2030. *Technological Forecasting and Social Change* **2017**, *117*, 84–97.

PERSPECTIVES ON AM: SUMMING UP…

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- Pure research phase has passed, commercialization ongoing
- ~0.1% of overall manufacturing market, but growing fast
- Biggest markets are EU, USA and China
  - Hardware manufacturers dominate, esp. for metal, polymer
  - Metal AM is the most mature; polymer AM is getting there
  - Software, automation increasingly important
- AM utility classified vs. complexity, customization and volume
- "Most probable future" scenario for AM in 2030 presented
- Implications (DS): Need agile AM systems with improved part quality and multi-material capabilities, supported by AM-specific design tools; must consider end-of-life issues <u>now</u>

THANK YOU FOR YOUR ATTENTION!