3D PRINTING IS POISED TO CHANGE YOUR BUSINESS

BUT HOW TO ADOPT IT IN YOUR OPERATIONS?

MORE THEN TECHNOLOGY DEVELOPMENT

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About us

- Yang Cheng
- Education
  - PhD in Operations Management from Center for Industrial Production, Aalborg University, Denmark, 2011
  - Master in Management Science and Engineering from Beihang University, China
  - Bachelor in Industrial Engineering from Beihang university, China
- Research
  - Associate Professor in Aalborg University (2015-)
  - Visiting scholar in Cambridge University, Osaka University, and Zhejiang University, etc.
  - Global operations, supply chain, technology management, knowledge transfer, servitization, sustainable operations

About us

- Henrik G. Larson

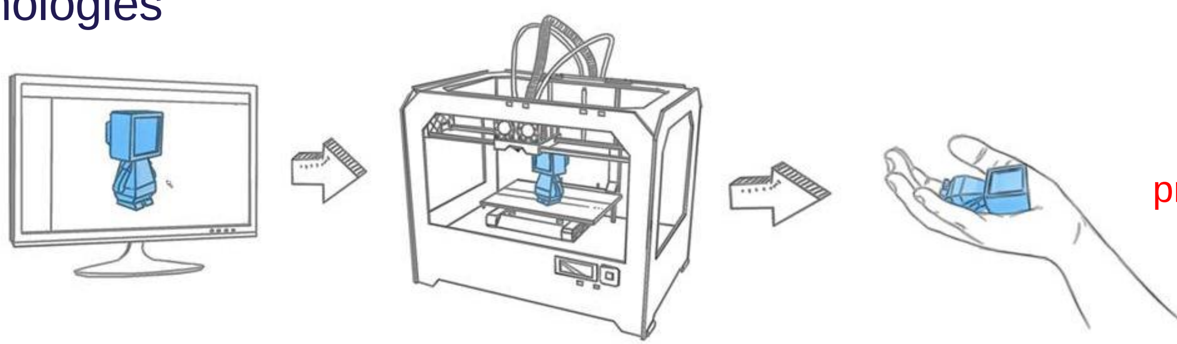
- Education
  - Master in Mechanical Engineering
  - Bachelor in Business Administration (HD)

- Industrial Business Experience
  - R&D manager at JSP in Hammel
  - Business Unit Director at DTI in Aarhus
  - CEO at CFI in Bjerringbro and Viborg

What is 3D printing (3DP)?

- 3D printing (3DP) also known as additive manufacturing
  - A digital technology for producing physical objects from a three-dimensional (3D) computer aided design (CAD) file layer by layer through a series of cross-sectional slices
  - Significantly different from the existing “subtractive” manufacturing technologies

3D CAD model



Final product

STL format files, which can be processed directly by 3D printers

Each slice of STL file representing 2D layer of object

2D layers sent to 3D printer one layer at at time

The object produced by building each layer on top of the previous one

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History of 3DP

1984: The development of SLA;
1986: 3D system established
1988: FDM
1989: Stratasys established

2002: Kidney produced by 3DP;
2004: Nano composite used in 3DP;
2005: First color 3D printer;
2007: Launch of open source project (RepRap) for 3DP;
2008: 3D printers using mixed materials

May: Stratasys acquired Solidscape;
June: Metal mandible printed by 3DP transplanted into human
June: Obama indicated the importance of 3DP;
Nov: 3D system acquired Zcorp;

1. Stratasys acquired MakerBot;
2. 3D sys acquired Phenix sys;
3. Inside 3DP conference
4. Nike first shoes produced by 3DP;
5. Graphene used in 3DP

1976: Laser cutting sheets and screwing them into 3D objects;
1979: Mold production using molds using layered manufacturing techniques

1991: LDM;
1992: SLS
1993: 3DP; ceramics used in 3DP;
1996: 3D printer appeared in media;
1997: Titanium used in 3DP

1. Car Urben produced by 3DP;
2. Airplane produced by 3DP;
3. 3D bio printer
4. Carbon fiber material used in 3DP

1. Merge between Stratasys and Objet;
2. Article on “The Economist”;
3. Pistol produced by 3DP;
4. NAMII established

2014: MJF;
2015: 3D sys China;
Materialise provided 3DP produced parts for Airbus;
2016: GE acuired Concept Laser and Arcam; 3D printer based on CLIP;

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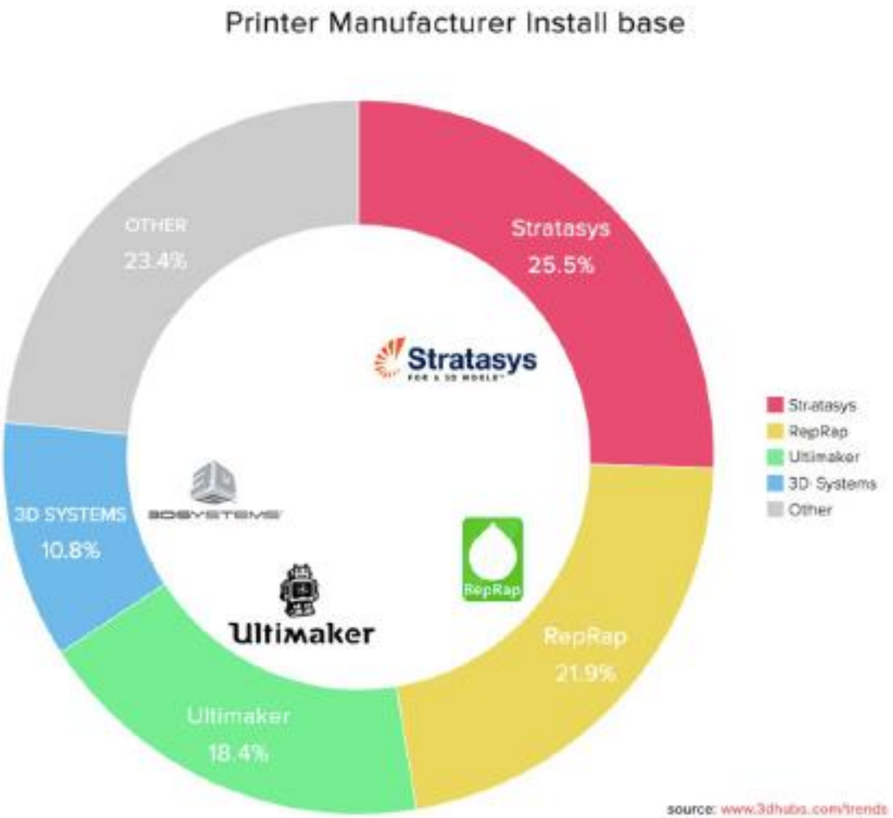
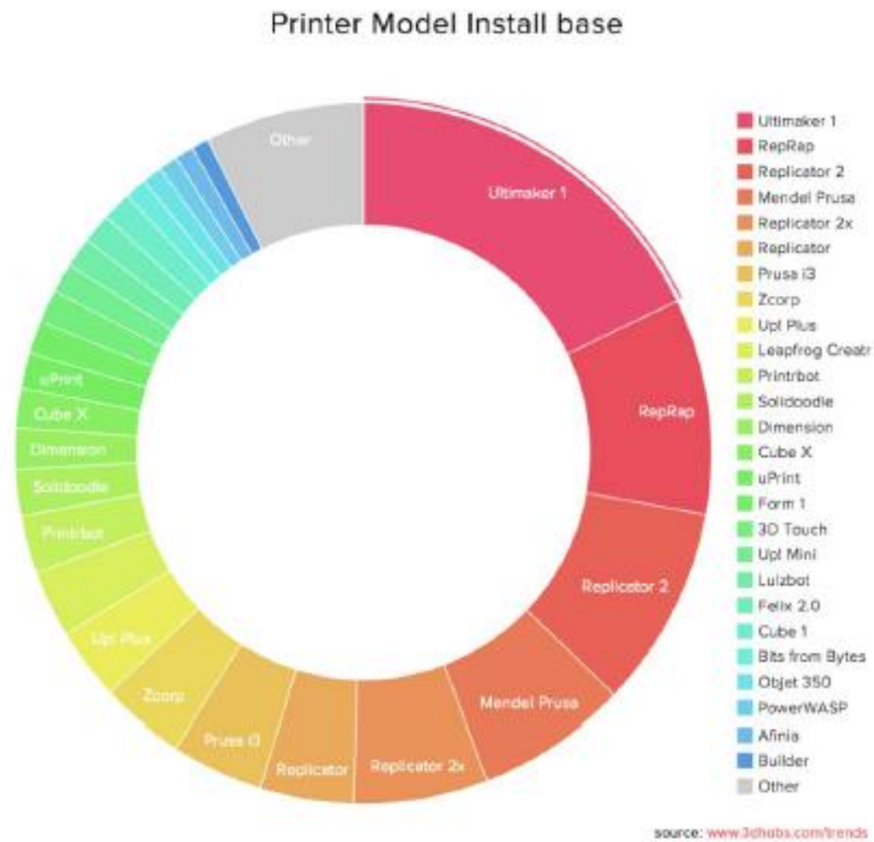
Main 3DP technologies and materials

Type	Technologies	Materials
Extrusion	Fused deposition modeling (FDM) or Fused filament fabrication (FFF)	Thermoplastics, eutectic metals, edible materials, Rubbers, Modeling clay, Plasticine, Metal clay (including Precious Metal Clay)
	Robocasting or Direct Ink Writing (DIW)	Ceramic materials, Metal alloy, cermet, metal matrix composite, ceramic matrix composite
	Composite Filament Fabrication (CFF)	Nylon or Nylon with short carbon fiber + reinforcement in the form Carbon, Kevlar, Glass and Glass for high temperature fiber
Light polymerized	Stereolithography (SLA)	Photopolymer
	Digital Light Processing (DLP)	Photopolymer
	Continuous Liquid Interface Production (CLIP)	Photopolymer + thermally activated chemistry
Powder Bed	Powder bed and inkjet head 3D printing (3DP)	Almost any metal alloy, powdered polymers, Plaster
	Electron-beam melting (EBM)	Almost any metal alloy including Titanium alloys
	Selective laser melting (SLM)	Titanium alloys, Cobalt Chrome alloys, Stainless Steel, Aluminium
	Selective heat sintering (SHS)[8]	Thermoplastic powder
	Selective laser sintering (SLS)	Thermoplastics, metal powders, ceramic powders
	Direct metal laser sintering (DMLS)	Almost any metal alloy
Laminated	Laminated object manufacturing (LOM)	Paper, metal foil, plastic film
Powder fed	Directed Energy Deposition	Almost any metal alloy
Wire	Electron beam freeform fabrication (EBF^3)	Almost any metal alloy

Main 3DP equipment providers

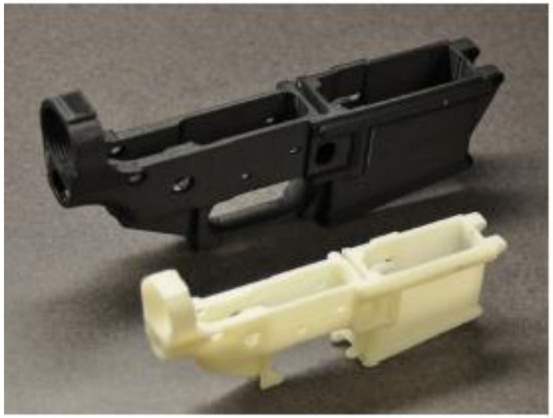


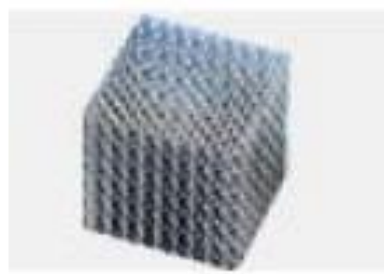


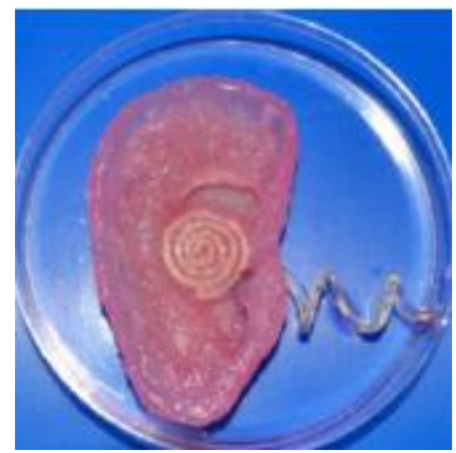
Adoption of 3DP in practice

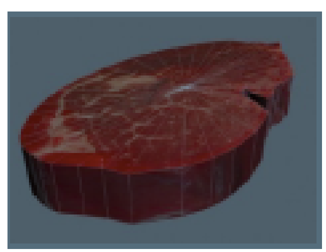
- **Automobile components:** While AM is not yet suitable for mass production, it is increasingly used to create components for high-end, specialized automobiles. For example, engine parts for Formula 1 race cars have been fabricated using direct metal laser sintering
- **Aircraft components:** While the parts resulting from direct metal AM processes are still not quite at critical components grade, there exist many instances of AM parts being used in aircraft. One example is an environmental control system duct on the F-18
- **Custom orthodontics:** Align Technology, Inc. uses AM to create clear, custom braces for thousands of patients across the global
- **Custom hearing aids:** Siemens and Phonak apply laser sintering to quickly fabricate custom hearing aids
- **Shoe manufacturer:** Timberland can produce a shoe model in 90 minutes for a cost of 35 US dollars by using a 3D printer

Adoption of 3DP in practice









Pros and Cons of 3DP

3DP VS. traditional manufacturing technologies

Pros

- Being capable of building complex geometries in a single step that cannot be fabricated by any other means; offering the utmost geometrical freedom in engineering design and thus customised products
- Ability to speed up product design and easily share and modify designs
- Eliminating the expensive tooling required by forming processes like molding, forging or stamping
- Creating functional parts without the need for assembly, saving both production time and cost and reducing complexity in business
- Minimal inventory risk as there is no unsold finished goods inventory
- Offering reduced waste; minimal use of harmful chemicals; and the possibility to limit energy used, use recycled materials, and reduce carbon footprint

Cons

- Higher costs (both machine and material costs) for large production runs relative to injection molding and other technologies
- Reduced choice for materials, colors, and surface finishes
- Lower precision relative to other technologies
- High calibration effort
- Quality of parts is in need of improvement; Rework of parts is often necessary (support structures)
- Limited strength, resistance to heat and moisture, and color stability

3DP: A new industrial revolution

- Cons lead to
  - Only be adopted in applications with low production volumes, small part sizes, and having complex designs
- Pros lead to
  - Potential to be as disruptive as the PC and the internet
  - A completely new system transforming the very notion of manufacturing in a “hugely creatively disruptive” way
- 3DP: A new industrial revolution
  - The transformation of manufacturing can be very wide-ranging
  - Leading to profound changes in the way many products are designed, developed, produced, delivered, and supported

Several ways 3DP is poised to change your business

- ***Way 1: Changes in the way products are designed and developed***
  - Reduce the need for time-consuming manual production of prototypes
  - A rival reduction of development cycle time and risk
  - More new designs without geometry limitation
  - Design, not products, would move around the world as digital files to be printed anywhere by any printer, thus potentially transforming product distribution much in the same way the MP3 did for music
- Potential challenge
  - There is a gap in knowledge as it relates to design-for-printing
  - Know-how to create designs to exploit the benefits of 3DP that cannot be accessed by traditional tools and efficiently translate the needs and wants of individual customers into precisely the right product for them

Several ways 3DP is poised to change your business

- ***Way 2: Changes in the way products are produced***
  - Assembly lines can be reduced or eliminated for many products, as the final product can be produced by AM in one process
  - Products could be customised based on individual specifications, making it easier and faster to address more niche markets
  - A given manufacturing facility would be capable of printing a huge range of types of products without retooling
- Potential challenge
  - Not every component is suitable for being produced by 3DP
  - Technical challenges involved in getting the most out of AM techniques, such as adjusting the properties of novel materials, setting environmental parameters to prevent shape distortion and optimize the print speed

Several ways 3DP is poised to change your business

- ***Way 3: Changes in the way products are delivered and supported***
  - Supply chains can be reduced or eliminated for many products, as the final product can be produced by AM in one process (no setup/changeover)
  - Production and distribution of material and products could be de-globalised as production is brought closer to the consumer
  - Products could be printed on demand without the need to build-up inventories (of e.g. spare parts)
  - Large regional warehouses could be replaced by smaller facilities with on-site 3DP capabilities
- Potential challenge
  - Understand the impact of 3DP adoption on (spare part) supply chain
  - Lifecycle costing (rather than direct cost) to understand cost structure and to guide new design of supply chains

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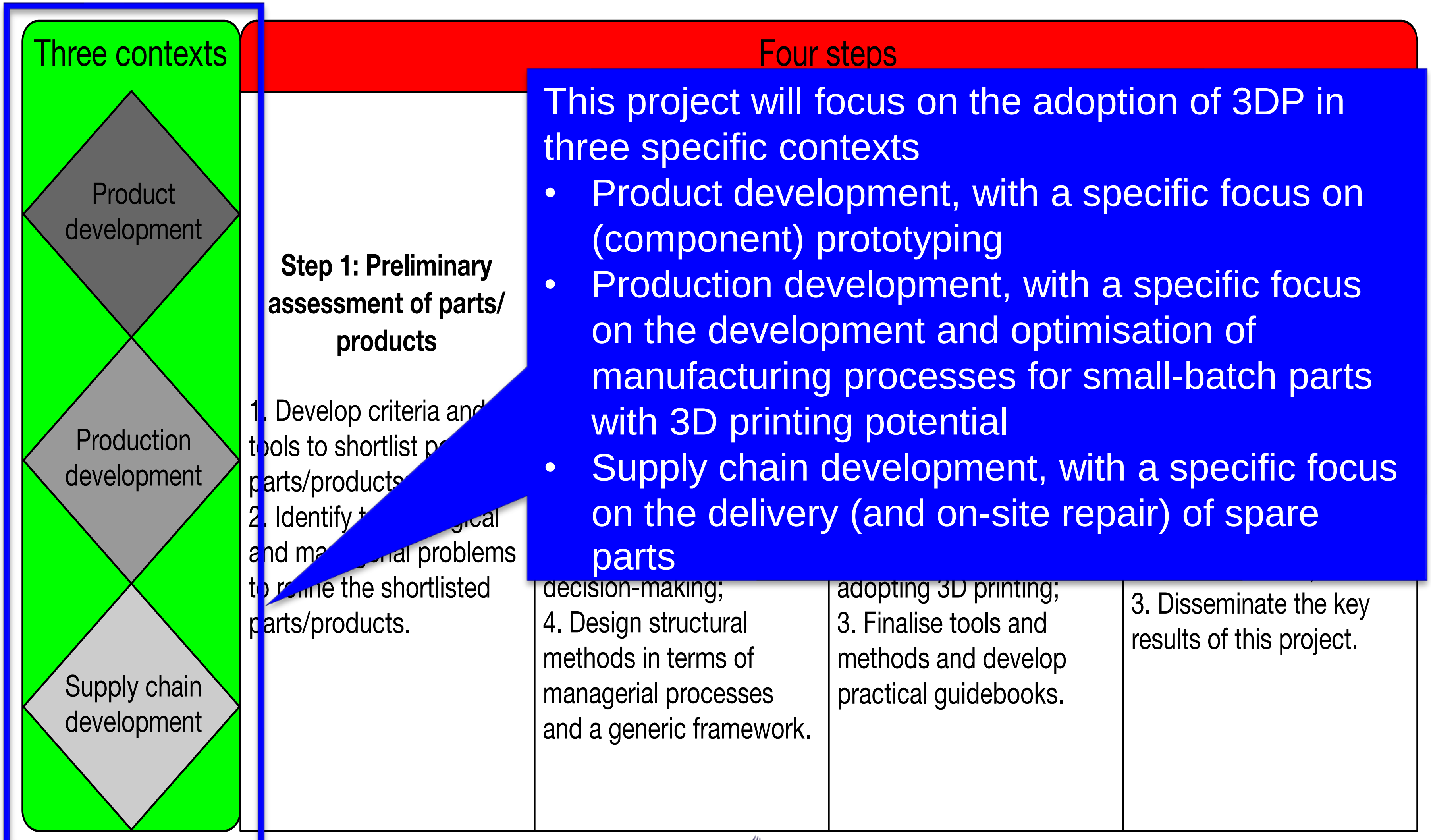
An ongoing project with Danish Wind Industry Association

- Challenges related to the adoption of 3DP in wind energy industry
  - Further development of technology
  - SMEs: Lack of resources and expertise
  - Limited research on helping SMEs
- An ongoing project aiming to
  - Address the influence brought by the adoption of 3DP to management system and organisation **rather than further developing technology**
  - Design a comprehensive management system and systematic approach to facilitate the adoption of 3DP in developing, producing, and delivering products for Danish SMEs
  - Improve competitiveness of Danish SMEs in the wind energy industry by transferring the relevant knowledge and helping them to adopt 3DP, while without facing risks

An ongoing project with Danish Wind Industry Association

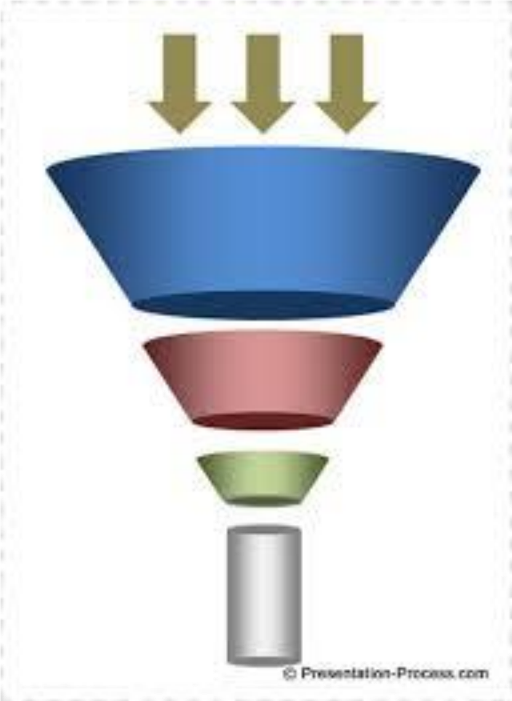


An ongoing project with Danish Wind Industry Association

Three contexts	Four steps			
Product development Production development Supply chain development	**Step 1: Preliminary assessment of parts/ products** 1. Develop criteria and tools to shortlist potential parts/products; 2. Identify technological and managerial problems to refine the shortlisted parts/products.	**Step 2: Development of structural tools and methods** 1. Establish scenarios for further analysis; 2. Identify factors related to 3D printing adoption; 3. Develop simulation tools and lifecycle-costing tools to facilitate decision-making; 4. Design structural methods in terms of managerial processes and a generic framework.	**Step 3: Test and completion of structural tools and methods** 1. Test and improve the developed tools and methods; 2. Explore synergies between the development of product, production, and supply chain when adopting 3D printing; 3. Finalise tools and methods and develop practical guidebooks.	**Step 4: Development of business cases** 1. Develop business cases to confirm the business potential of adopting 3D printing; 2. Conceptualise business models; 3. Disseminate the key results of this project.

Step 1: Preliminary assessment of parts/products

- Step 1: Preliminary assessment of parts/products
  - No ”one-size fit –all” approach
  - Companies must choose the most appropriate approach based on multiple factors
  - Bottom-up + top-down
- Two–step Approach
  - Screening process
    - Develop criteria and processes to shortlist potential parts/products
  - Quantitative methods
    - Select parts/products suitable for 3DP



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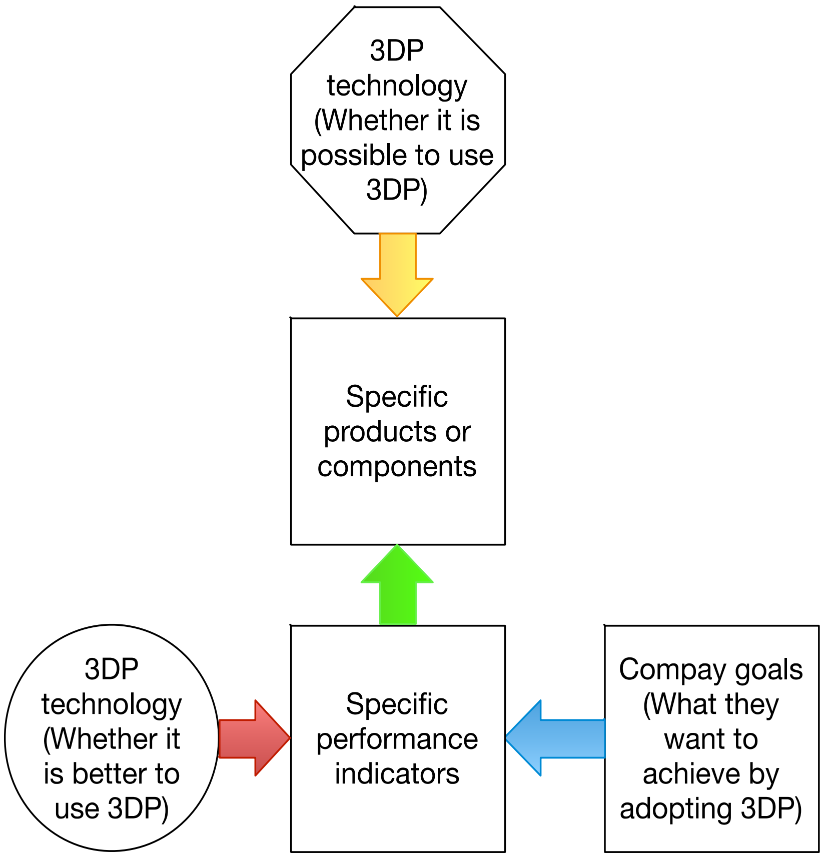
Screening process



- Identifying company goal: what company wants to achieve by adopting 3DP?
  - Prototype, tooling, and spare parts
- Specifying performance objectives regarding each area: whether it is better to use 3DP?
  - Take the characteristics of 3DP into consideration
  - Roughly judge whether it is feasible to improve the chosen performance by adopting 3DP in their specific contexts

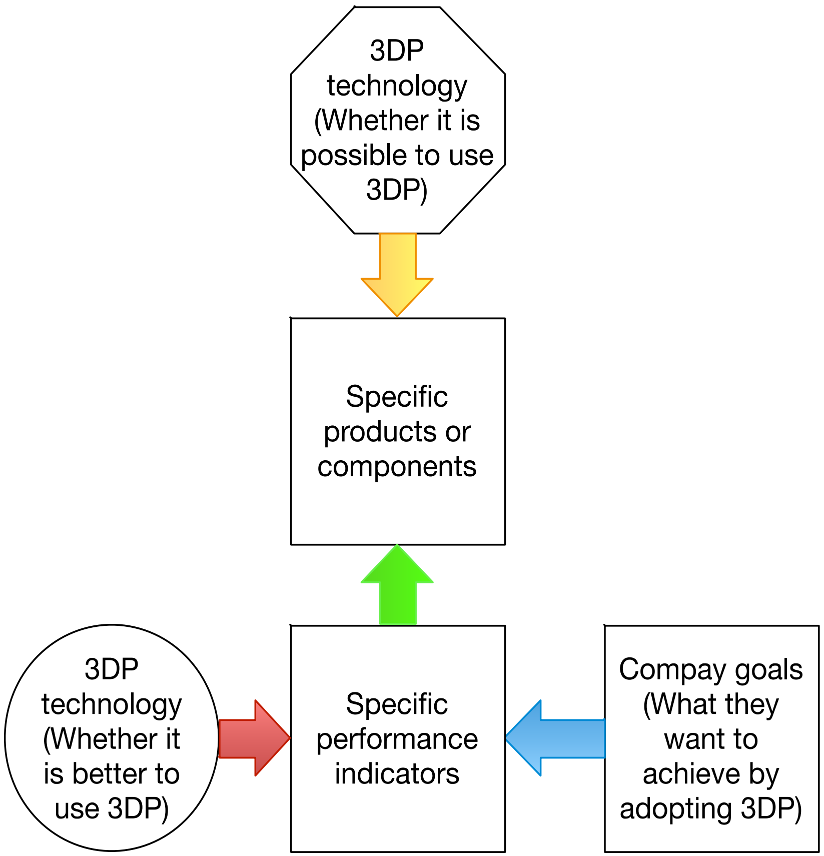
Screening process: potential performance objectives

For prototype:
- Geometric freedom
- Functional integration
- Prototype development time reduction
- Reducing overall development time
- Reducing prototyping costs
- Flexibility to make prototypes anytime
- Improve the overall design of the product
- Reduce product development risks

For tooling:
- Geometric freedom
- Functional integration
- Few number of tools
- Fulfil short warning changes from customers
- Tooling cost reduction
- Reduce process steps in tooling production
- Tool development lead time reduction
- Improve flexibility in tool making
- Improve tool life
- Reduce coolant usage in the tool
- Reduce tool changeover time

For spare parts:
- Inventory/delivery cost reduction
- Lead (delivery) time reduction
- Supply risk reduction
- Downtime (cost) reduction
- Reducing carbon foot print across life cycle
- Reducing potential loss of business
- Shorter and more transparent supply chain
- Improved service level and Increased availability of suitable materials (reduction of stock-out cost)

Screening process



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- Specifying performance objectives regarding each area: whether it is better to use 3DP?
  - Take the characteristics of 3DP into consideration
  - Roughly judge whether it is feasible to improve the chosen performance by adopting 3DP in their specific contexts
- Screening all products/components: choosing the ones with most potential
- Finalising the shortlist of products/components: whether it is possible to use 3DP regarding physical requirements (size, weight, surface, etc.)

Thanks for your attention!
Welcome to join us:

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