Additive Manufacturing

A Playbook on How to Adapt to Additive Manufacturing

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IDEE | Institute of Innovation, Design and Engineering

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1st Edition

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Additive Manufacturing: The Playbook on Adapting your Business to AM

1st Edition

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ADAPTION

How can additive manufacturing and the relevant processes be integrated into existing and new business models, and how can they be built up sustainably?

This Playbook is an inspiration that helps to check all relevant aspects in the corresponding environment and specific phase.

The playbook provides an orientation framework for a correct interpretation and approach to additive manufacturing and helps companies to successfully adapt to that technology.

MSE Business Engineering and Production
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WHY THIS PLAYBOOK?

The theory that additive manufacturing is used and applied only in prototyping is a general view on that technology. This is because of the lack of knowledge about the process and its full potential.

A lot of information and knowledge about the technology has been extensively documented from various sources. About the implementation or adaptation of the complete process of additive manufacturing and its benefits, however, not nearly as well-founded.

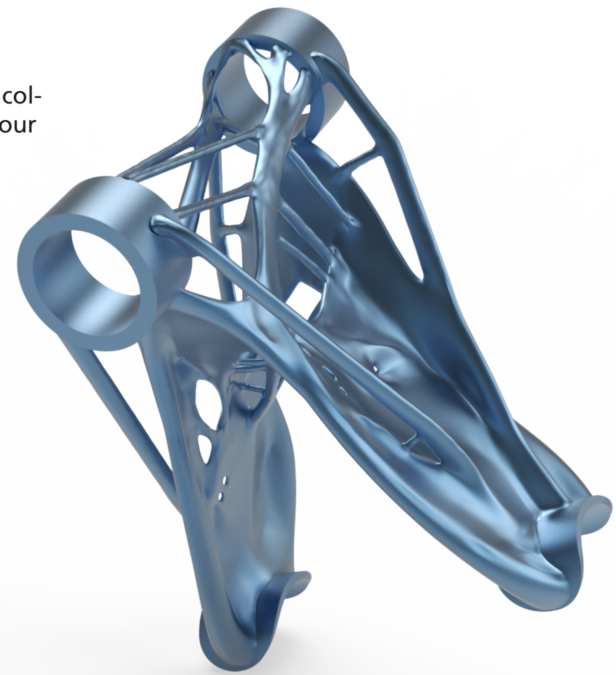
Although statistical surveys show a growth and a technological development regarding AM, real life experiences show a different picture.
The level of knowledge in the companies hardly allows a strategic planning and a development that takes into account the new technology Additive Manufacturing.

Knowing that AM exists and what it does, is actually not enough to know, since it does not simply replace any product systems like CNC, injection molding, casting etc. It is rather re-thinking the whole product development approach and its benefits in terms of resources, cost, time, supply chains, sustainability and added value, for the manufacturer and end-user.

The fields of application in AM are diversified. However, the potential in certain areas has not yet been recognized.

This Playbook will give you and your colleagues a good orientation to start your own AM adoption journey.

Be inspired and have fun!



Steering column bracket

If you don't know why it looks like that, its about time to dive into the additive manufacturing universe

WHAT YOU WILL LEARN

PREJUDICES AGAINST ADDITIVE MANUFACTURING

Whether eating utensils, artificial knee joints, screws, car tools or aircraft parts. The areas of application for 3D printing are numerous. The prejudices are at least as diverse.

3D PRINTING WILL BE IMPORTANT, BUT WILL NOT REVOLUTIONIZE OUR WORLD.

That's wrong. 3D printing will revolutionize the world. Whether in two or five years, we can argue about that. It will happen faster in one industry than in another. Fact is, the technology and the processes behind it are turning everything we've used up to now on its head. Products will be completely redesigned, with different functional integration than we've known before. We compare the change brought about by additive manufacturing with the change we have experienced through the Internet and are still experiencing. 3D printing will be important, but will not revolutionize our world.

IT IS QUITE ENOUGH TO BUY A 3D PRINTER AND PRINT PRODUCTS WITH IT.

No, that's not enough. At least not if you want to fully exploit the true value of the technology. This is also proven by numerous evaluations and analysis.

From design to purchasing, from production to logistics: the networking of areas is aligned along the product and thus the value creation. This changes the concept of work: from performance-oriented to customer-oriented work.

THE TECHNOLOGY IS NOT YET READY, AND PRINTERS ARE NOT YET PRODUCING THE QUANTITIES.

The fact is, the speed and accuracy of printing systems is constantly increasing and improving over short time.

We can no longer think only in terms of conventional development cycles as before. There are completely new ways to make development even faster. This means that time estimates of over 5 years are at best a conservative estimate. It is more likely to go even faster.

PREJUDICES AGAINST ADDITIVE MANUFACTURING

JUST NETWORK THE PROCESSES FOR ADDITIVE MANUFACTURING IN THE EXISTING BUSINESS - AND THAT'S IT.

A revolution would not be a revolution if only some parts changed. The changes will be much more comprehensive. Other business models will disappear or change. For example, in the area of logistics, which will no longer necessarily transport products over long distances, but will distribute them more regionally.

In the future, users will be able to download components from servers and print them, just like an MP3. Intellectual properties and the process for applying for patents will have to be rethought because they can no longer keep up with the speed of development.

The production supply chain will change, eliminating the need to stock tools and components. Printing on demand of spare parts will become possible.

THESE CHANGES SCARES US. WE JUST STAY THE WAY WE ARE AND WAIT TO SEE WHAT COMES.

Companies are already starting to reorganize their processes and implement an overarching view (total cost of ownership). Nothing is as constant as change - everyone should try to see this as an opportunity.

Despite all the change, the human being remains at the center: The business model of the dental lab may disappear, but the competent technician who can operate the scanner and the 3D printing machine will still be needed.

Change doesn't have to mean anything negative. 3D printing is something exciting. Take an active role in shaping the transformation for your business.

Remember: Change is pain!

LET'S CONSTRUCT A FRAMEWORK

SETTING THE SCOPE AND INGREDIENTS OF OUR MATRIX

We need some kind of boundary and structure to orient ourselves for the big AM adaption journey. It is best to set up a framework in form of a matrix. The matrix can have a chosen number of rows and columns. In our example for the ease of use we will define 3 rows and 3 columns, resulting in 9 cells.
The 9 cells will be filled with a set of trigger questions, jobs to be done, topics and deliverables, from a specific point of view from the structural and process organization. But first we will explain the each point separately.

OUR 3 MATRIX COLUMNS

The 3 columns represent the level of knowledge maturity. From the need of basic information to the ability of deploying the whole plan. It also can be seen as a chronological order. The levels in this playbook will be defined a as following:

"The Insight"
As the basic level of required knowledge.

"The Roadmap"
As the ability to see and create feasible concepts of roadmaps.

"The Deployment"
As the capability of making the right decisions for implementing the created businessplan and go live.

OUR 3 MATRIX ROWS

The 3 rows represent the point of views from different employment positions in a company. It ranges from a shop floor manager up to the perspective of an chief executive officer.

THE CONTENT OF THE 3X3 CELLS

Now that we have 9 fields of different knowledge levels and perspectives we efficiently can define the scope of each matrix cell.
The content will be outlined with trigger questions, topics and deliverables.

TRIGGER QUESTIONS

Trigger, is the lever of a firearm to release a shot of ammunition. Or if something triggers an event or situation, it causes it to begin to happen or exist. ...the incident which triggered the outbreak of the First World War. Imagine a questions that causes a certain thinking about a topic.

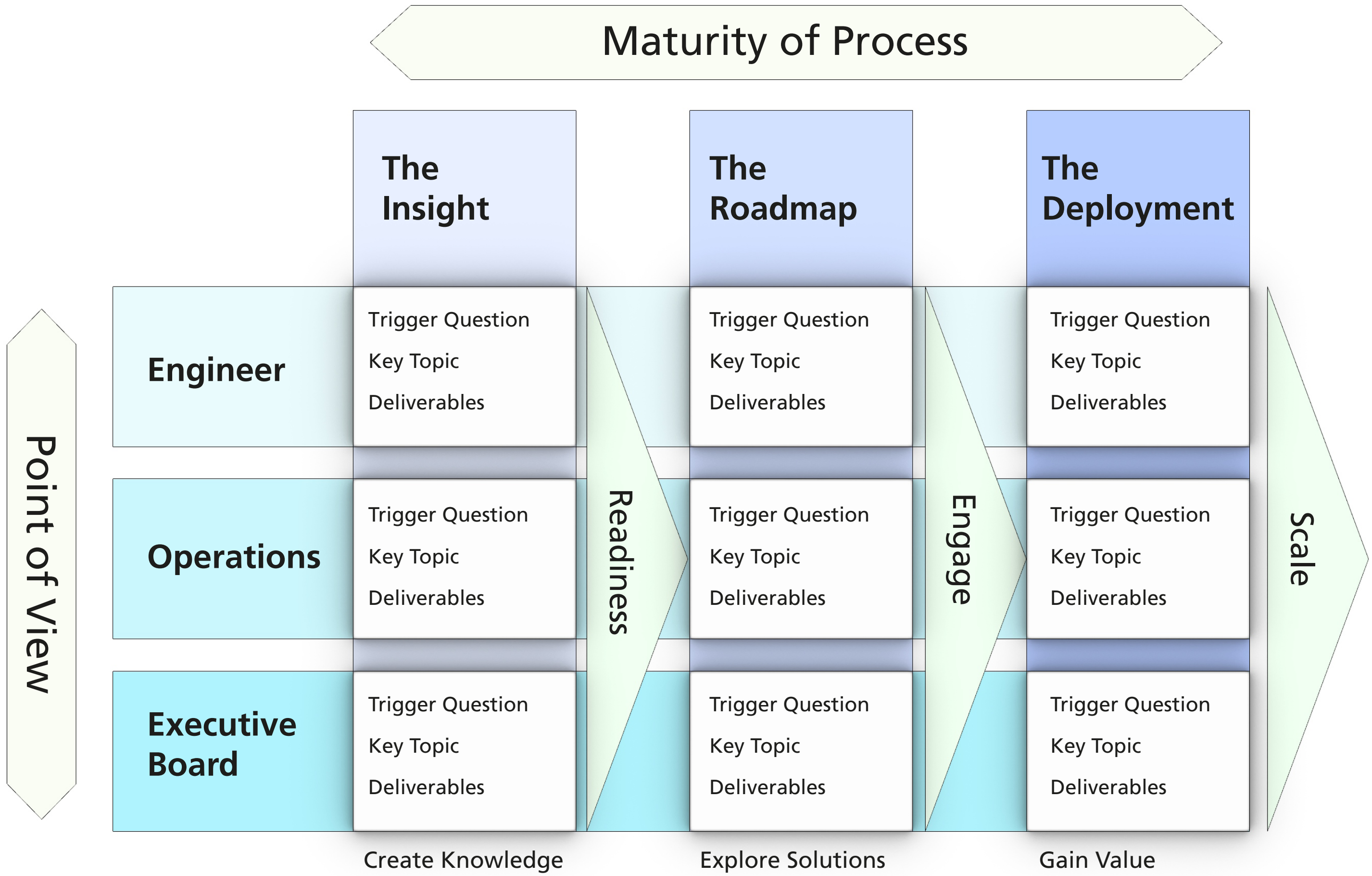
KEY TOPICS

Topics that correspond to the stated trigger questions, help not to get to far off and lost in researching the topic. In each cell a number of relevant topics will be defined in respect to the specific knowledge level and the point of view.

DELIVERABLES

There is always a secure feeling when you have a clear definition of the goal to be achieved. Not the ultimate goal but clear stage or intermediate goals. Step by step to the peak...

THE MATRIX EXPLAINED



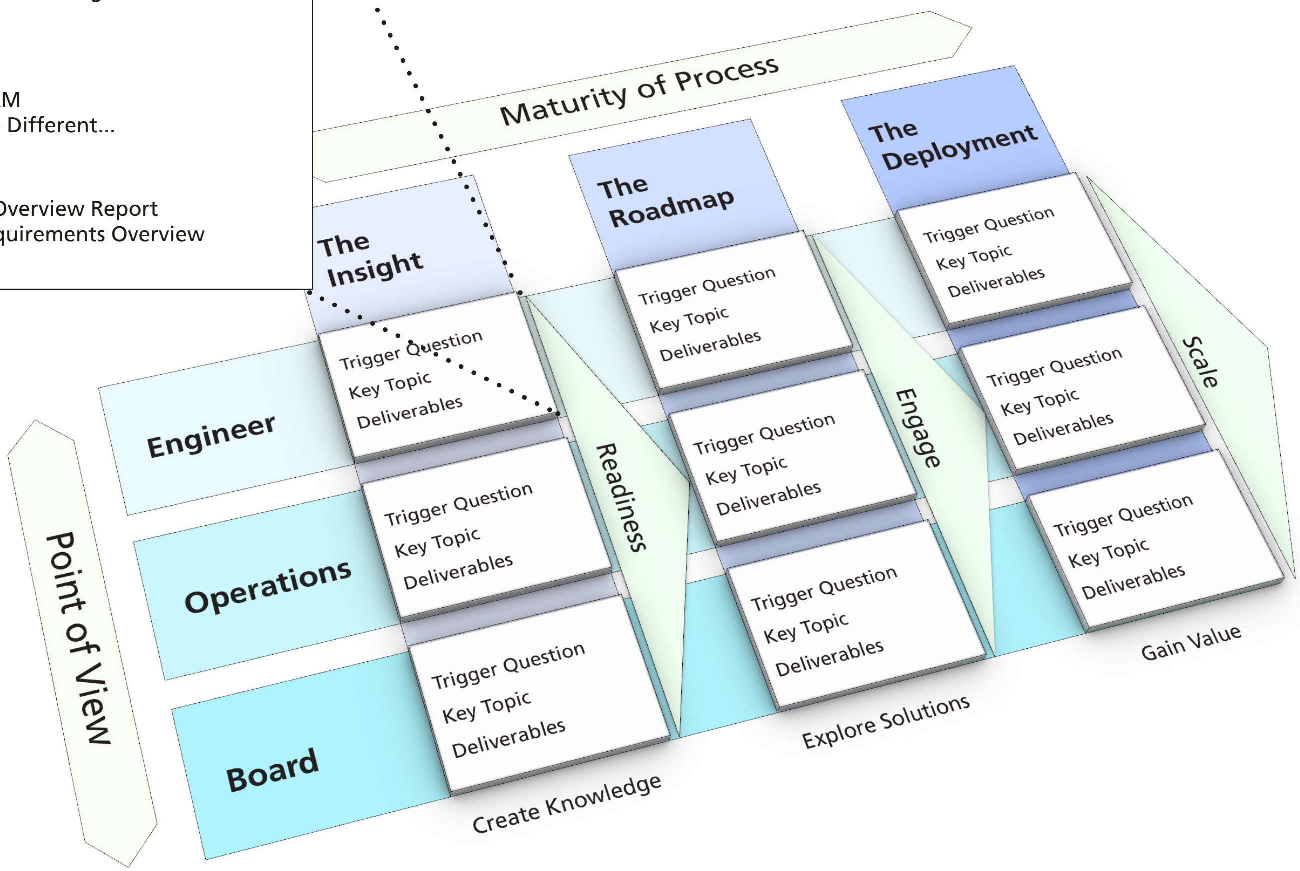
THE MATRIX EXPLAINED

WHAT ENGINEERS NEED TO KNOW

Trigger Question
What is Additive Manufacturing
What are the advantages
How...

Key Topics
Experience AM
Knowing the Different...

Deliverables
Technology Overview Report
Software Requirements Overview



A CLOSER LOOK ON THE POINT OF VIEW

STRUCTURAL AND PROCESS ORGANIZATION

The matrix columns "Levels of knowledge maturity" can be applied to a wide range of business organization with intention to adopt to AM and is not needed to adjust. But the rows, represent a certain point of views in an organization, which can differ form company to company. It is recommended that you review your own structural organization and adjust the points of view accordingly.

While the organizational structure defines the framework conditions, i.e. which tasks are performed by which persons and/or material resources and with which rights persons are endowed. The process organization regulates the work and information processes that take place within this framework.

Take a minute and analyse, if your existing structure and processes fit your intention of adoption. Eventually it needs to be adjusted for your new business intention.

Here's a quick definition, in case you can't remember.

What is organizational structure?

The organizational structure divides the tasks of a company into task areas, determines the departments and the positions that are to process them. As a result, a structure appears as a combination of these basic organizational elements, which can be represented as an organizational chart.

What is process organization?

Process organization builds on the results of the organizational structure by linking the individual tasks and the operations required to perform them. The work processes must run in an orderly manner in the company.

ORGANIZATIONAL STRUCTURES

FUNCTIONAL STRUCTURE

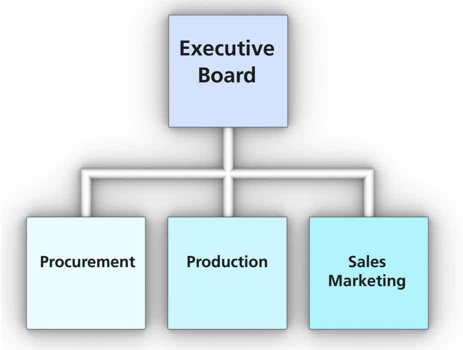
This form of organization results in a task-oriented structure in which the units and departments are divided according to activities and functions.

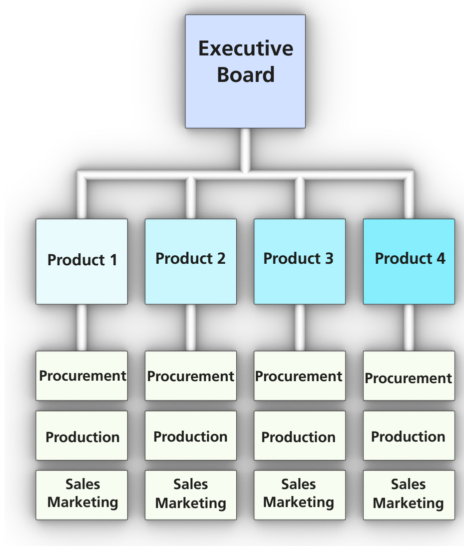
DIVISIONAL STRUCTURE

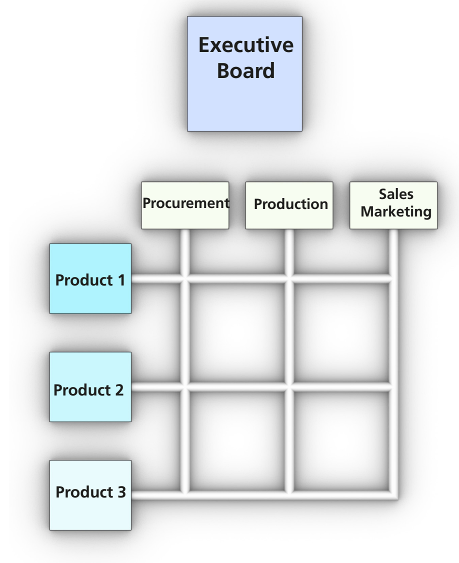
In the divisional structure, the object comes first, which is divided at the next level according to various functions such as purchasing or production. This is an organization according to business units or products, also known as a divisional organization.

MATRIX ORGANIZATION

In matrix organization, there is an overlap between functional areas and product areas of the company. Here, for example, a specialist area works for several divisions or products.







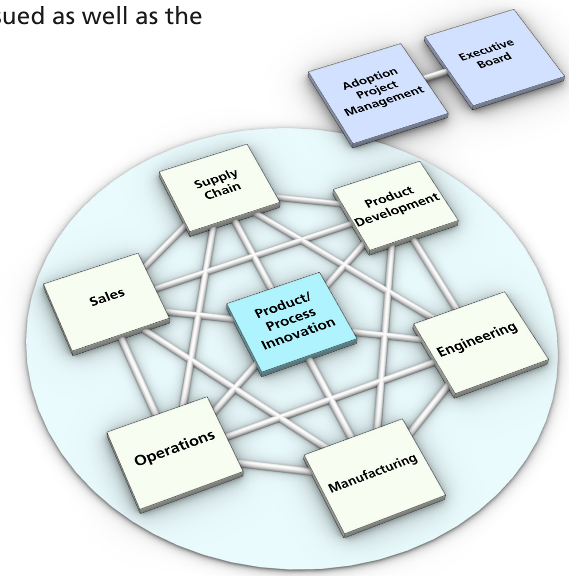
ORGANIZATIONAL STRUCTURES

SHUFFLE IT UP AND RECONFIGURE

New technology, new production and automation processes require a change and adjustment of the existing structure. Change is pain! Some employees fear that their job position could be at stake. Some engineers may also worry that AM will render their traditional engineering skills obsolete. For on-boarding a AM adoption project team, don't pick the most experienced but the most intuitive and open minded person for a position. A shift in process thinking is required. Engineers must contend with the way in which AM re-frames the design process, condensing formerly discrete tasks performed by various engineering functions into a larger, less linear undertaking.
Maybe it is a valid approach to omit any known organizational and process structures and rebuild it according to the new business model.

Bring AM out of the shop floor and into the office to complete the alignment of the enabling elements and value proposition. It is all too easy for innovative technologies to remain in the hands of specialists and enthusiasts, but AM's potential suggests that it should be understood and planned for at the business value level. The elements considered crucial for enabling AM, from QC to talent and workforce, span business functions and typically require investment and planning. The emphasis and required scope of the enabling elements depend on the type of value and path being pursued as well as the quality requirements and complexity of the parts being made. The form these enabling elements will take and the degree to which investments might be necessary can be further defined by measuring their impact against the organization's operating, financial, and strategic objectives.

May be a project team organization is a good approach.



THE PERSONA

SAMPLE PERSONA BASED ON THE “POINT OF VIEW” SEGMENTATION ON OUR MATRIX

Persona (lat. mask) are fictitious descriptions of selected representatives of a target group. This means that a single persona represents the characteristics and usage behavior of an entire target group. Usually there are 3-6 personas defined. The description of the persona starts with the name, goes through socio-demographic to behavioral characteristics. We define a persona, that represents an archetype of a job role or position. In our matrix there are three segmentations. To illustrate these persona a general segmentation of a common organizational structure is performed.

For your own adaption journey, choose and define a project team and document each member. Here you find relevant topics to analyse and reflect on the affected worker.

The segmentation herein:
1. **Engineering / Technical**
2. **Operation / Business Development**
3. **Executive / Board / Finance**

DESCRIPTION AND PAIN POINTS OF THE TEAM MEMBERS

- Personal Information
- Role and responsibilities in the company
- Goals and values
- Pain Points and challenges
- Prejudice against AM
- Information and research sources

THE PERSONA

SO WHAT IS THE CONCRETE BENEFIT OF A PERSONA?

Imagine the following situation:
You were on vacation and now you are telling various people from your circle of friends, co-workers or family about it.

WHAT DO YOU TELL YOUR GRANDMOTHER?

About the blue sea and the beautiful flowers on the hotel grounds, about the friendly people there, the clean hotel and the well-organized journey.

WHAT DO YOU TELL YOUR FRIENDS?

Certainly not about the clean hotel room. But about the good-looking young entertainers, the wild nights in the hotel bar and the flirtations at the pool.

SO WHAT DO YOU DO?

You tell them what corresponds to their interests.

And that is exactly the benefit of a persona. It is precisely defined that you have a good idea of what they are interested in - and what story you need to tell.

In the same approach you can follow in a business transformation process, addressing new or existing clients or find new product ideas.

PRO TIP:

Get a copy of the “Design Thinking Playbook” from the creative authors: P. Link, M. Lewrick, L. Leifer

design-thinking-playbook.com

THE ENGINEER REVEALED

PERSONAL INFORMATION

Michael Buehler

- 35 Years
- M. Sc. Mechanical Engineering
- CAS Industrial Design
- Married
- 2 Kids

CHARACTER AND TRAITS

- Innovative thinker
- Team player
- Always present and available
- Open minded
- Trusting
- Arrogant
- Weekend athlete

ROLE AND RESPONSIBILITIES

- Product development unit manager
- Responsible for 15 engineers and designers
- Implement a multi-year strategy and engagement plan
- Drive integration of partner/services capabilities
- Set and maintain KPI's related to manufacturing
- Provide guidance to Manufacturing technology regarding design concepts and specification requirements to best utilize equipment and manufacturing techniques

GOALS AND VALUES

- Innovator, not a rocket scientist
- Relies on partners and service providers
- Not afraid of failing
- Safety is key
- Provides strong support

INFORMATION AND RESEARCH SOURCES

- Industry Blogs
- Suppliers & job contacts
- White papers
- Industry researcher
- Reddit, You Tube
- Trade shows

THE ENGINEER REVEALED

PREJUDICE AGAINST AM

- The Status Quo is good enough for the Company
- AM doesn't have enough Value
- No Precision
- No Reliability
- No Strength
- Price

PAIN POINTS AND CHALLENGES

- No experience with AM
- No experience in AM conform CAD
- The worst thing you can have is a non-reliable system.
- Level of precision, surface finish, materials, speed, accuracy
- Negative market perception
- New system = new problems
- Quality needs to be close to injection molding
- Can compromise, but is it good enough?
- Materials – environmental impact, usage, limitations
- Which is the right system and process

OTHER POSSIBLE ROLES AND FUNCTIONS IN THAT SEGMENT

- Design Engineering
- Product Development
- Process Engineering
- Manufacturing Technology

SCOPE OF KNOWLEDGE TO ACQUIRE JOBS TO BE DONE

- Technology Overview
- Standard Process
- Implementation to existing processes
- Terminology
- Facts and Figures
- Software
- Stakeholders
- Materials
- Feasibility
- Gain value
- Freedom and rules of part design
- Innovation creation
- AM based Product development

PRO TIP:

Get a copy of the books and business canvases from the Business Model Champions: A. Osterwalder, G. Bernarda and Y. Pigneur

strategyzer.com

THE OPERATIONS MANAGER REVEALED

PERSONAL INFORMATION

Sue Mc Murphy

- 30 Years
- B. Sc. Business Administration
- CAS General Management
- Married
- 3 Cats

CHARACTER AND TRAITS

- Strategic thinker
- Leader
- Always busy
- Respectful
- Considerate
- Cautious
- Voluntary Community work
- Cat lover

ROLE AND RESPONSIBILITIES

- Operations Manager
- Operations efficiency
- Employee productivity
- In close correspondence with HR
- Industry knowledge
- Reports to CEO, General Manager
- Process optimization

GOALS AND VALUES

- Strategist not a innovator
- Managing people
- Afraid of making the wrong decisions
- Keeping all balls in air
- Sustainability

INFORMATION AND RESEARCH SOURCES

- Business Network
- Employees
- Magazines
- Google
- Linked In
- Networking events

THE OPERATIONS MANAGER REVEALED

PREJUDICE AGAINST AM

- AM will disrupt business in a negative way
- Very challenging to standardize processes
- Exchanging long-term employees
- What works today is outdated tomorrow
- Productivity
- High Investments

PAIN POINTS AND CHALLENGES

- No knowledge in AM
- No process knowledge
- Finding the right crew
- Defining jobs for new processes
- Business Transformation
- Sourcing of whatever is needed
- Align stakeholders
- Making the right decision
- Finding and analyzing relevant process cases

OTHER POSSIBLE ROLES AND FUNCTIONS IN THAT SEGMENT

- Director of Operations
- Program Manager
- Operations Supervisor
- Factory Manager

SCOPE OF KNOWLEDGE TO ACQUIRE JOBS TO BE DONE

- Technology Overview
- Standard Process
- Implementation to organizational structure
- Terminology
- Facts and Figures
- Recruiting the right employees
- Corporate knowledge management
- Factory Setup
- Production planning
- Winning new clients, not loosing any existing
- Marketing alignment
- Launch control and adjust new operations

PRO TIP:

Switch your perspective as you would build up a business model from scratch not trying to prevent any disruption. Be courageous and inspire yourself!

THE CEO REVEALED

PERSONAL INFORMATION

Bill Farelane

- 62 Years
- Master Business Administrator
- 20+ years CEO experience
- Divorced
- 4 adult kids

CHARACTER AND TRAITS

- Needs Proofs
- Wants results
- All about numbers
- Baby Boomer
- Ready for Change
- Respectful
- Networker
- 24/7 availability

ROLE AND RESPONSIBILITIES

- Chief Executive Officer
- Overviews Operations
- Adjusting Organizational Structures
- Reports to Board of Directors
- Company Strategy
- Driving Revenues
- Management Buy-in

GOALS AND VALUES

- Keeping Staff Engaged
- Bottom line profit growth
- Sustainable Business Development
- Maintaining a competitive edge through innovation and new technology

INFORMATION AND RESEARCH SOURCES

- Wall Street Journal
- Forbes
- Gartner
- Not Google
- Price Waterhouse & Coopers
- Other Big Company CEO's

THE CEO REVEALED

PREJUDICE AGAINST AM

- No known scalable success story in business sector
- Clients don’t accept the “feel” of AM Surface
- ROI not feasible
- Technology Hype
- A solution to an non-existent problem
- Limited possibilities

PAIN POINTS AND CHALLENGES

- No knowledge in AM
- No process knowledge
- Finding relevant Facts and Figures
- Defining new Organizational Structures
- Business Transformation
- Seeing it as a Whole
- Staying Competitive
- Making the right decision
- Finding and analyzing relevant business cases

OTHER POSSIBLE ROLES AND FUNCTIONS IN THAT SEGMENT

- Managing Director
- President
- Chair
- Director of Operations

SCOPE OF KNOWLEDGE TO ACQUIRE JOBS TO BE DONE

- Technology Overview
- Standard Process
- Evaluating Business Potential
- Defining organizational structure
- Terminology
- Facts and Figures
- Risk and Return
- Risk Diversification
- Opening new markets
- Ability to make the right decision
- Overall Growth
- Implementation Strategy
- Chance Management

PRO TIP:

New Technology brings new possibilities and value. Be a pioneer and don’t wait to be eaten for breakfast by the competitors. Read about the stories of Kodak, Polaroid and Blockbuster. Don’t be one of them.

HITTING THE RIGHT SPOT

MICHAEL IS MOST INSPIRED IF HE...

...sees a lot of images and pictures
...can relate infos to own processes
...gets very specific technical information
...has the possibility to get his hands on

CAREFUL NOT TO...

...get lost in the scope
...be overwhelmed by trying everything out
...forget the true plan
...disrespect decisions by the project teams

SUE IS MOST EFFICIENT IF SHE...

...can choose from few sets of concepts
...gets enough general information on a topic
...sees what knowledge is required
...has the availability of the right employees

CAREFUL NOT TO...

...settle too early on an idea
...choose the path with least resistance
...forget the importance of the product development

BILL DECIDES BEST IF HE...

...sees a lot of success stories
...can relate numbers to own company
...gets the big picture
...has the possibility to proof everything

CAREFUL NOT TO...

...omit creative approaches
...be overtightened with investments
...disrespect the potential of new technology
...wear the traditional approach hat

Focus on the capability of the technology for new product development and beneficial processes

Focus on the alignment of stakeholders, employees, process organization and factory impacts

Focus on the impact on the organization, investments, buy-ins, new market and risk assessment

PRO TIP:

Find the best information source streams for additive manufacturing and related processes, for each persona.

THE 3 KNOWLEDGE MATURITY LEVELS

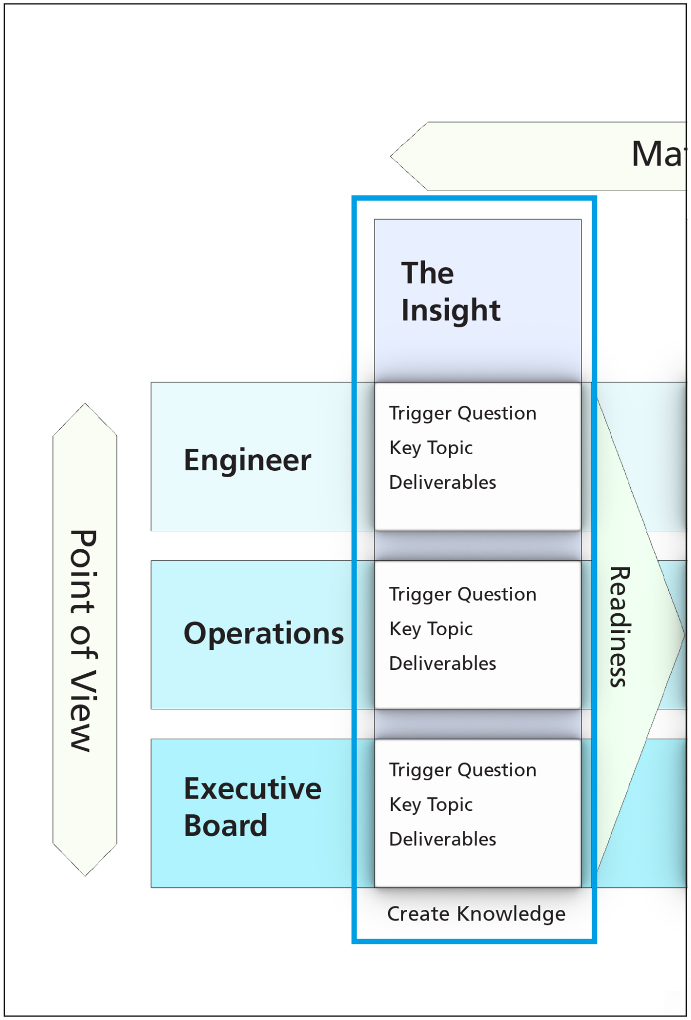
KNOWLEDGE LEVEL 1 “THE INSIGHT”

Let’s dive into additive manufacturing knowledge and processes

COLUMN "THE INSIGHT"

Goal: Create AM Knowledge

In this knowledge level phase, a basic understanding of the technology and processes is applied to all point of views



ENGINEER POINT OF VIEW

Trigger Questions

What is Additive Manufacturing?

What are the advantages compared to traditional manufacturing?

How is it done?

Key Topic

Experience AM

Knowing the different technology, material and systems

Terminology

Design approach for AM

Fundamentals of the production process

Deliverables

Technology Overview Report

Use Cases of comparable Industries

Software requirements overview

Research checklist

Activity checklist

COLUMN "THE INSIGHT"

Goal: Create AM Knowledge

OPERATIONS POINT OF VIEW

Trigger Question

What is Additive Manufacturing?

What are the challenges?

What business segments use it?

Key Topic

Experience AM

Identify and understand the key benefits

Implementation Pain points

Business Segments that use AM potential

User Journey

Deliverables

Technology Overview Report

Use Cases of comparable Industries

Defined Pain points addressed

Research checklist

Activity checklist

EXECUTIVE POINT OF VIEW

Trigger Question

What is Additive Manufacturing?

What are actual numbers and figures?

What is the transformation impact on the business?

Key Topic

Experience AM

Identify and understand the key benefits

Transformation Pain points

Cost and Investments

Deliverables

Technology Overview Report

Use Cases of comparable Industries

Case Numbers and Figures

Research checklist

Activity checklist

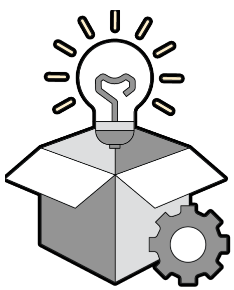
GENERAL PROCESS OVERVIEW

A GLOBAL VIEW ON THE ADDITIVE MANUFACTURING PROCESS

1.

PRODUCT DEVELOPMENT

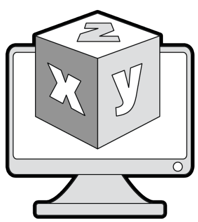
The best AM journey starts with the development of the product. Not just adopting new manufacturing possibilities to an existing product.



2.

DESIGN FOR AM

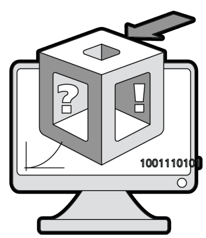
Additive says it all . Not subtractive nor casting or bending. Align your perspective and question what you know about traditional manufacturing.



3.

CAE AND GENERATIVE DESIGN

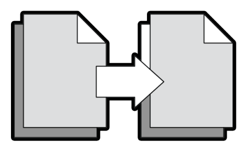
Digitally test, calculate and optimize strengths and material usage. Generative design can be the key.



4.

DATA FILE TRANSFER

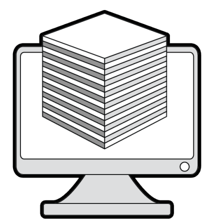
You might know your native CAD file format and .stp .iges very well. AM needs meshes not nurbs. Know, how to handle them.



5.

PRINT PREPARATION

It's like preparing .nc files in CAM for your loved CNC machine. In AM its quite similar and called slicing. Similar doesn't mean easy.



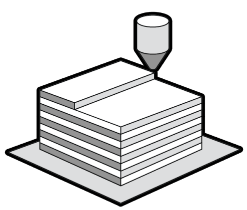
GENERAL PROCESS OVERVIEW

A GLOBAL VIEW ON THE ADDITIVE MANUFACTURING PROCESS

6.

THE PRINTING ITSELF

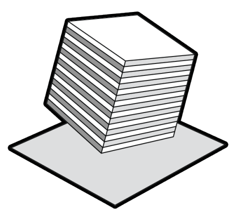
Yes, the part which is everybody fiercely focusing on. We'll get into detail of the most used technologies later.



7.

REMOVE THE FINISHED COMPONENT

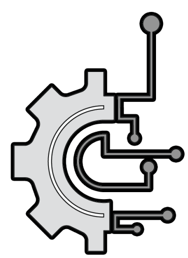
This is easy and rewarding. But still a step to be planned in the process. Which is done manually or automated.



8.

POST PROCESSING

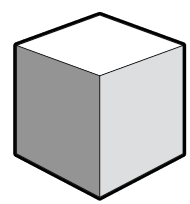
Most 3D prints need to be post treated and processed. Each AM technology requires a specific process.



9.

THE FINISHED COMPONENT

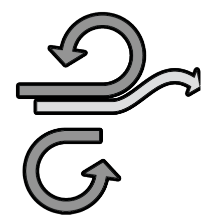
Well Done!



10.

DOWNSTREAM, LOGISTICS AND CIRCULAR ECONOMY

This is something that heavily relates on your business model. On demand, decentralized and mass customization are topics to be planned in the very beginning. The AM loop closes.



MAJOR PRINTING TECHNOLOGY

**GENERAL OVERVIEW ON THE MOST USED 3D TECHNOLOGIES
AND REFERENCE IN MATERIALS**

EXTRUSION PRINTING TECHNOLOGY

For all processes: three-dimensional structures are created by the selective layer-by-layer process.

MATERIAL EXTRUSION - (MEX)

Material extrusion is a 3D printing process in which polymer filament or pellet material is forced through a heated extruder nozzle and melts. The printer deposits the material over a predetermined path on the build platform, where the filament then cools and hardens into a solid. These methods are called:

FDM
Fused Deposition Modeling

FFF
Fused Filament Fabrication

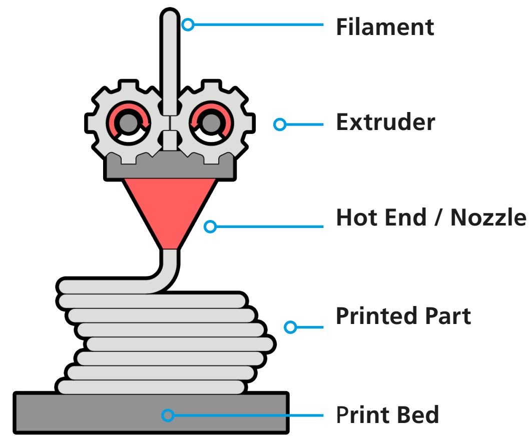
CFF
Continuous Fiber Fabrication

PEM
Paste Extrusion Modeling

FDM and FFF is the same technology, but FDM terminology is from the manufacturer Stratasys, where some believe it will become registered as a protected definition.
Fused deposition modeling is considered the most cost-effective process and offers fast results in rapid prototyping. For end products, this process is only suitable if appropriate post-processing is carried out to smooth the visible layers. For mechanically stressed objects, it is suitable if in addition to the material, the direction of pressure and thus the direction of the layers are also taken into consideration.

FDM / FFF FILAMENT

Fused Deposition Modeling

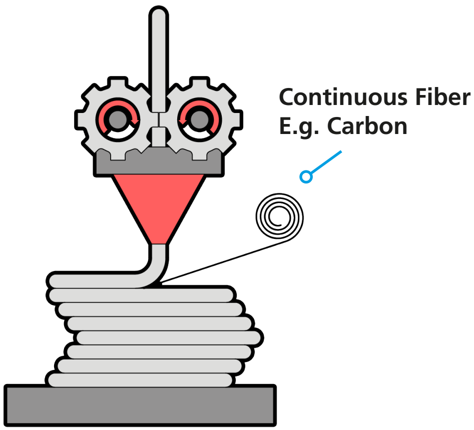


ADVANTAGES OF THE FDM PROCESS

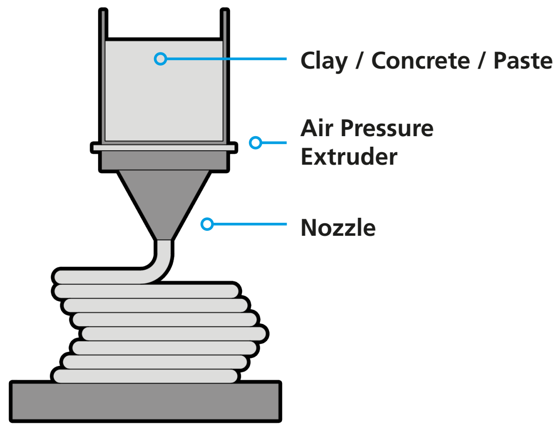
- Inexpensive printers and material
- Compared to other 3DP processes it is the fastest
- Best known and most established technology
- Wide range of materials
- Availability of water soluble materials

EXTRUSION PRINTING TECHNOLOGY

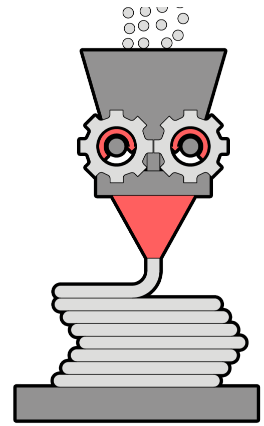
CFF
Continuous Fiber Fabrication



PEM
Paste Extrusion Modeling



FDM / FFF PELLETS
Fused Deposition Modeling



DISADVANTAGES OF THE FDM PROCESS

- The rough (0.12 - 2.0mm) layered structure of the objects does not produce smooth surfaces.
- Layered surface look and feel is hardly accepted by the end-user
  The layers determine in which direction an object can absorb forces.
- Tensile forces perpendicular to the printing direction can contribute to the layers separating more quickly.
- When designing objects to be printed with fused deposition modeling, these properties must be taken into account and constructed accordingly.
- Depending on the used material, it may be necessary to perform post-processing.

POWDER BED FUSION TECHNOLOGY

For all processes: three-dimensional structures are created by the selective layer-by-layer process.

POWDER BED FUSION - (PBF)

Powder bed fusion is a 3D printing process in which a thermal energy (Laser) source selectively melts powder or a binding agent (Glue) fuses the powder particles within the build area. Many powder bed fusion printers also employ a technique that simultaneously deposits and smooths the powder during the production process, so that the finished object is surrounded and supported by loose, unused powder

These methods are:

SLS
Selective Laser Sintering

SLM
Selective Laser Melting (only for Metal)

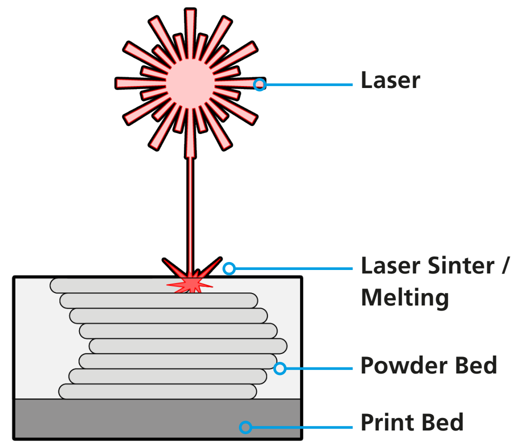
MJF
Multi Jet Fusion (Color Option)

BJ
Binder Jet

One of the greatest advantages of this process is the possibility to create overhanging structures. The powder, which is not fused, also serves as a support structure for overhangs and cavities. In addition, this process is very resource-saving, since powder that is not fused can be removed with an air gun and reused for the next print job. With colored binders colored prints can be produced. PBF Printers are currently more expensive than FDM/FFF devices.

SLS

Selective Laser Sintering

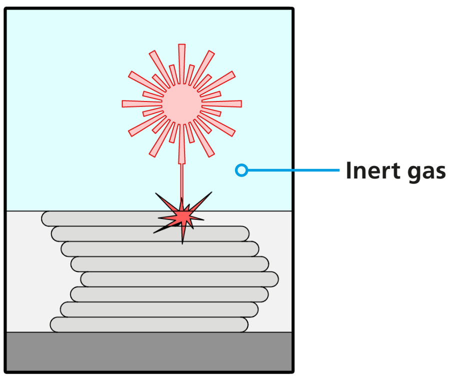


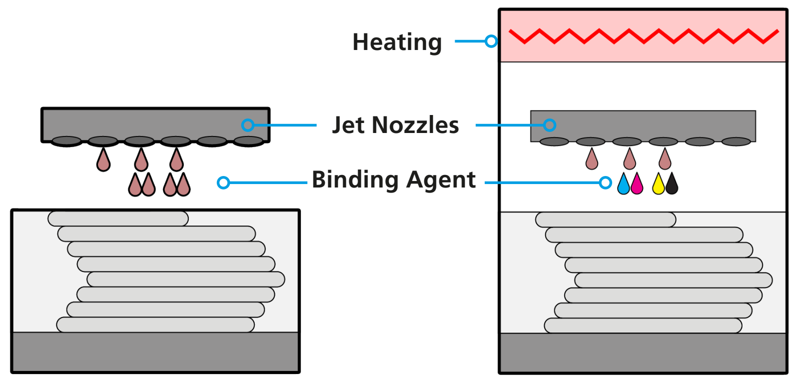
ADVANTAGES OF THE PBF PROCESS

- Great Freedom of Design
- Requires no support structure
- Best for producing strong, functional parts with complex geometries
- Unused material can be re-used
- Almost invisible print layers
- High level of accuracy

POWDER BED FUSION TECHNOLOGY

SLM	**BJ**	**MJF**
Selective Laser Melting	**Binder Jetting**	**Multi Jet Fusion**
Metal Only		Color Option





DISADVANTAGES OF THE PBF PROCESS

- Expensive Material
- Messy powder handling
- Print size rather small
- Expensive machines
- The machines require skilled operators to use
- Lack of AM conform constructions, prevents maximum benefits (Latticing, generative design, etc.)
- Cool-down time of SLS up to 12 hours. This leads to longer production time
- Parts have a grainy surface without any post-processing
- Thermal distortion

VAT POLYMERIZATION TECHNOLOGY

For all processes: three-dimensional structures are created by the selective layer-by-layer process.

VAT POLYMERIZATION (VPP)

Vat polymerization uses a vat of liquid photopolymer resin, of which the model is constructed layer by layer. An ultraviolet (UV) light or laser beam is used to cure or harden the resin where required.

As the process uses liquid to form objects, there is no structural support from the material during the build phase, unlike powder based methods, where support is given from the unbound material. Support structures, must be taken into consideration during the modeling process. Resins are cured using a process of UV photo polymerization or laser, where the light is directed across the surface of the resin with the use of motor controlled mirrors. Where the resin comes in contact with the light or laser, it hardens. To achieve the best possible hardness, the printout is additionally UV light post cured.

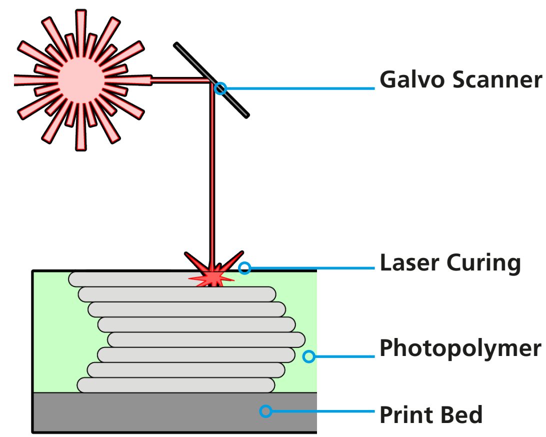
SLA
Stereo Lithographie

DLP
Direct Light Processing

The VP-Process has a high level of accuracy and good finish but often requires support structures and post curing. The process of photo polymerization can be achieved using a laser SLA or a projector DLP. Recoating blades pass over previous layers to
ensure that there are no uneven material cumulation for the next layer. The photo-polymerization process achieves a smooth surface finish due to the build material being liquid. Typical layer thickness for the process is 0.025 – 0.5mm.

SLA

Stereo Lithographie

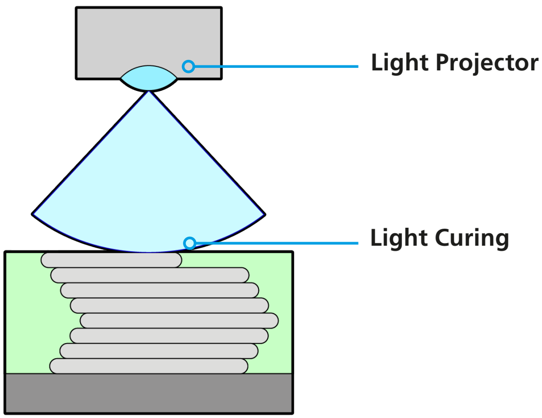


ADVANTAGES OF THE VP PROCESS

- Smooth surface finish
- Fine layer resolution
- Best for producing detailed objects
- Unused resin can be re-used
- DLP printers are non-expensive
- Investment casting resin available

DLP

Direct Light Processing



DISADVANTAGES OF THE VP PROCESS

- SLA printers are expensive
- SLA slow printing
- Resin handling
- Post UV curing
- Non structural parts
- Resin is very toxic

DO YOUR OWN IN-DEPTH RESEARCH

There are many other 3D Printing technologies available, they build up on the same principals but are very specific in the use.
The intention of this playbook, is surely not to go full fledge and in depth about any available printing technology. That would result in a whole book for itself!

Make sure you understand the concept of the 3 technologies described previously. These are the most implemented nowadays.
Once you have the feeling of a AM technology could fit your intention, do a in-depth research to gain more knowledge of the process, limitations and material.
Don't worry, we'll help you how to choose the right application for your intention.

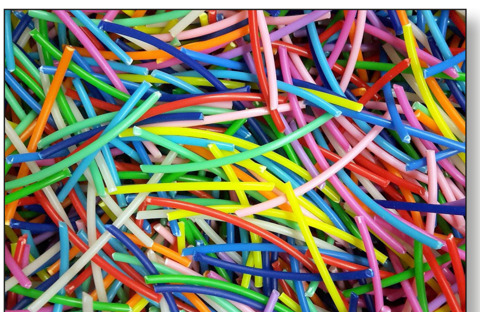
MOST COMMON MATERIALS FOR FDM / FFF

The FDM / FFF Extrusion technology is performed with various polymers in form of filaments

PLA **(Polylactic Acid)**
Is one of the most popular materials used in 3D printing. It is the default filament of choice for most extrusion-based 3D printers because it can be printed at a low temperature and does not require a heated bed. PLA is a great first material to use as you are learning about 3D printing because it is easy to print, very inexpensive, and creates parts that can be used for a wide variety of applications. It is also one of the most environmental friendly filaments on the market today. Derived from crops such as corn and sugarcane, PLA is renewable and most importantly biodegradable.

ABS **(Acrylonitrile Butadiene Styrene)**
Has a long history in the 3D printing world. This material was one of the first plastics to be used with industrial 3D printers. Many years later, ABS is still a very popular material thanks to its low cost and good mechanical properties. ABS is known for its toughness and impact resistance, allowing to print durable parts that will hold up to extra usage and wear. ABS also has a higher glass adaption temperature, which means the material can withstand much higher temperatures before it begins to deform.

PETG **(Polyethylene Terephthalate Glycol)**
PETG filaments are known for their ease of printability, smooth surface finish, and water resistance. It is a semi-rigid material with good impact resistance, but it has a slightly softer surface which makes it prone to wear. PETG is the perfect filament to combine strength and ductility, which is why it's used in so many mechanical parts and robotics. It has great chemical resistance with good water, acidic and alkalic resistance. The material also benefits the plastic to cool efficiently with almost negligible warpage.



MOST COMMON MATERIALS FOR FDM / FFF

Carbon Fiber Filled
Carbon fiber filaments use tiny fibers that are infused into a base material to improve the properties of that material. These fibers are extremely strong and cause the filament to increase in strength and stiffness. This also means that the 3D printed parts will be much lighter and more dimensionally stable, as the fibers will help prevent shrinking of the part as it cools. However, due to the added fibers, these materials are more likely to clog and may require special nozzles to avoid excessive wear.

PC **(Polycarbonate)**
Is a high strength material intended for tough environments and engineering applications. It has extremely high heat deflection, and impact resistance. Polycarbonate also has a high glass adaption temperature of 150° Celsius. This means it will maintain its structural integrity up to that temperature, making it suitable for use in high-temperature applications. It can also be bent without breaking and is often used in applications where some minor flexibility is required.

PVA **(Polyvinyl Alcohol)**
Is a soft and biodegradable polymer that is highly sensitive to moisture. When exposed to water, PVA will actually dissolve, which makes it a very useful support structure material for 3D printing. When printing extremely complex shapes or ones with partially enclosed cavities, PVA supports can be used and easily removed by dissolving in warm water. Standard supports may be difficult to print or remove in these situations.

MOST COMMON MATERIALS FOR PBF

The PBF printing technology, as the name implies requires powder based materials

Powders

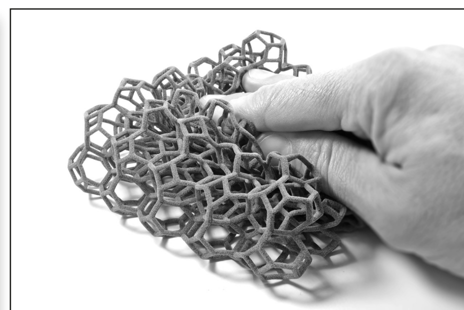
A key advantage of PBF is that it needs no support structures. The unsintered powder provides the part with all the necessary support. For this reason, SLS can be used to create free form geometries that are impossible to manufacture with any other method.
The quality of printed objects depends on various factors including powder properties such as particle size and shape, density, roughness, and porosity. Furthermore, the particle distribution and their thermal properties affect a lot on the flow-ability of the powder. PBF will provide a broader range of options with multiple nylons as well as a TPU for elastomeric prototyping, compared to MJF and BJ. SLS parts can be dyed in a variety of colors. Currently, Multi Jet Fusion only offers part built in PA12. These parts are Grey, but can be dyed black for improved cosmetics.
In general, the material diversity for PBF is limited.

PA12 (Polyamide / Nylon)

Is a tough material with high impact strength, elongation and durability. It has long term dimensional and mechanical stability and has excellent abrasion resistance, good chemical and weather resistance. The material is non reactive to water, oils, fats and spirits. It is flexible when thin but rigid when thick. PA12 Nylon parts have good temperature resistance. Thick parts will remain dimensionally stable in temperatures close to 182 °C while thin parts will start to soften and loose their shape when temperatures exceed 100°C.

TPE (Thermoplastic Elastomer)

TPE shows advantages that are typical for both plastic materials and rubbery materials. On the one hand, it is elastic, with an elongation at break of roughly 200%, which is more than tested within PA group of materials. It can be covered with a sealer which makes it water- and airtight. TPE can be compared to vulcanized caoutchouc (rubber) which is characterized by durability and elastic deformation. But unlike caoutchouc, TPE can be used in additive manufacturing which makes it ideal for footwear prototypes, hoses, gaskets and tubes.



MOST COMMON MATERIALS FOR VAT

The vat printing technology requires resin based materials

Resins

There are a lot of resins materials available on the market, all with different mechanical properties and prices.
In contrast to FDM, where polymer filament is used from a known material with certain mechanical properties, SLA and DLP 3D printers use resins where mechanical properties are obtained by the chemical composition of the resin. Because of the difference in chemical composition of the resin, the mechanical properties are very important and will help to compare different resins. Mechanical properties help choosing the right resin for the application. In many cases a 3D-printing resin suppliers provides a set of mechanical properties for each material. Different combinations of monomers, oligomers, photo-initiators, and various other additives that comprise a resin result in different material properties. There is no VAT resin material on the market today that compares to polycarbonate, nylon or other robust FDM materials in terms of strength and mechanical properties.
In addition, resin materials are more expensive to 3D print. Due to the liquid state, the resins are defined for example as wax-**like**, ABS-**like**.

Castable Resin

Vat 3D printers are more and more commonly used in jewelry casting due to their superior precision, speed and availability of castable resins. Instead of manually sculpting investment patterns in castable wax, modern jewelers and manufacturers create a 3D CAD model for printing. With 3D printed jewelry it is possible to get more repeatable results and significantly reduce human error. Castable resins are photopolymers designed to be functional equivalents of wax. Heated to temperatures reaching well over 750°C, they burn out, leaving ash residue of max 0.003%.

Tough Resins

Tough resins are for applications requiring materials that could withstand stress or strain for short periods of time. As such, these resins are extremely stiff, resistant to cyclic loads, and very strong. Common applications include sturdy, shatter-resistant parts like enclosures or seat belt clasps and high-performance prototypes. Vat tough resins are ideal for wearable technologies, gadgets and fine precision prototyping. VAT tough resins do have a few drawbacks. For instance, these resins typically have a low heat deflection temperature and are relatively brittle compared to other plastics.

METAL PRINTING NEEDS MORE ATTENTION

Metal printing bears some difficulties in the process, but once tamed, unleashes great benefits.

In general

Metal printers can be used for small batch manufacturing, but the capabilities of metal 3D printing systems resemble more the manufacturing capabilities of FDM or SLA machines than that of SLS printers: they are restricted by the available print area, as the parts have to be attached to the build platform.
The metal powder in SLM is highly recyclable. Usually less than 5% is wasted. After each print, the unused powder is collected, sieved and then topped up with fresh material to the level required for the next built, like in the polymer based SLS process. Waste in metal printing comes in the form of support structure, which are crucial for the completion of a build, but can increase the amount of the required material drastically. Support structures are always required in metal printing, due to the very high processing temperature and they are usually built using a lattice pattern. Support structures are required during printing for a variety factors, either to ensure accuracy while a part completes the curing or hardening process or to maintain tolerances and shape for delicate features. In the case of SLM, once the metal is melted it becomes denser than the surrounding unsintered powder and can sink through the powder and break off the part or otherwise warp.

Commonly used metal powders

- Steel/Iron and based alloys
- Nickel and based alloys
- Titanium and based alloys
- Aluminum and based alloys

Limits of metal printing

- Powdered metal is much more expensive than “regular” raw metal
- Speed of production is comparatively slow for regular objects
- Sometimes surface finishing and post-processing is needed
- Tolerance and precision are usually lower in comparison with CNC machining
- Additional heat treatment may be required to reduce inner stress of the 3D printed object
- Designing for metal 3D printing is more complex to other manufacturing methods.

PRO TIP:

If your goal is to proceed with metal additive manufacturing, do a thorough investigation on the limits, processes and cost-benefit ratios. Metal printing is quite a different story and can’t be “tested and learned by doing” by buying a inexpensive desktop printer.

TERMS YOU WILL COME ACROSS

A very rough cheat sheet of abbreviations and terms

ABS	Acrylonitrile Butadiene Styrene is an opaque thermoplastic and amorphous polymer
AM	Additive Manufacturing, commonly known as 3D printing in which 3D object is fabricated by adding layer-upon-layer of material and fuse them together
BJ	Binder Jetting is a 3D printing technique where a binding liquid is selectively deposited to join powder material to form a part
Build envelope	Build envelope is the maximum volume the printer can print and determines how large an object the printer can build
Build plate	Also known as Build platform or Bed, is the surface or area of the 3D printer on which parts are formed.
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CNC	Computer Numerical Control
Cura	Cura is an open-source 3D printer slicing application
DLP	Direct Light Processing is part of vat photo polymerization AM method where a photopolymer liquid resin is cured to make hard plastic parts
DMLS	Direct Metal Laser Sintering
Extruder	A 3D printer head module which pushes the filament through the Bowden tube to the hot end using two counter-rotating gripping wheels
FDM	Fused Deposition Modeling
FFF	Fused Filament Fabrication

TERMS YOU WILL COME ACROSS

A very rough cheat sheet of abbreviations and terms

Fill / Infill	The interior structure of a 3D printed object. To avoid wasting time and material by printing solid objects, the interior of the objects are printed with a mesh type structure. The infill is typically expressed as a percentage
G-code	G-code is the file format used to store information that can be interpreted by CNC machines and 3D printers
Hot end	Material extrusion method additive manufacturing uses a material extruder that gets hot enough to melt plastic
Material Extrusion	3d printing where a continuous filament of thermoplastic is used to construct 3D parts
Mesh	3d geometric object surface triangulation,
MJ	Material Jetting
MJF	Multi Jet Fusion
Nozzle	The part of the hot end of the printer that deposits the melted plastic material.
OBJ	Object file – A geometry definition file format from 3D modeling programs commonly used in 3D printing.
Overhang	Parts or features of a 3D model that protrudes or overhangs at an angle over 45 degrees without any support below when orientated on the build platform are generally categorized as overhangs
PA	Polyamide / Nylon
PBF	Powder Bed Fusion
PC	Polycarbonate
Photopolymer	A polymer that changes its properties when exposed to light.

TERMS YOU WILL COME ACROSS

A very rough cheat sheet of abbreviations and terms

PLA	Polylactic Acid – A biodegradable thermoplastic polymer made from plant starch, used as a 3D printer material.
PP	Polypropylene
PVA	Polyvinyl Alcohol – A water-soluble filament often used as support material in 3D printing.
Raft	The raft is a removable filament latticework printed horizontally onto the build platform as support to minimize warping.
Shell	Also referred to it as the outline or outer perimeter, this describes the outermost wall of the printed 3D object
SLA	Stereolithography Apparatus
Slicer / Slice	A software to convert the digital 3D file into a machine-readable code. The slicer cuts the model into very thin horizontal layers called slice and generates tool paths in the two-dimensional plane.
SLM	Selective Laser Melting
SLS	Selective Laser Sintering
STL/.stl	Known as the Stereolithographic file, it is the most common file format 3D printers use.
Support	3D objects with large overhangs or gaps require removable supports to stop it collapsing during printing. In some instances, these are printed using different material to the main part material.
TPU	Thermoplastic Polyurethane
Vat Photopolymerization	Vat photopolymerization is an AM method where a light source is used to cure/harden photopolymer liquid resin
Voxel	In 3D printing, a voxel represents a value on a regular grid in a three-dimensional space, like a pixel with volume.

THE SOFTWARE

Yes, you need some additional software for best performance in the process

THE AM PROCESS PHASES

As of today, there is no all-in-one software that serves for the whole AM process, but they start evolving and entering the market.
In each process stage a specific software type is used and recommended.

- Product development
- CAD
- CAE
- Slicing

This section will give you a good reference of what the software should be capable of. Every business that adapts and shifts to AM, already uses a software that is intended to be used continously. A shift means, not only investment for acquiring but also for training. Since there are uncountable software manufacturers with their specific USP and millions of supporting plug-ins, we give you some non-binding recommendations and hints.

PRODUCT DEVELOPMENT

Imagine that your business model is **Mass Customization** - we'll get back for details, later in the book.

Orthosis manufacturer already have such a business model, since every part of the human body is unique and the concept one-fits-all does definitely not work in that context. Moving on with new technology, requires transforming analog processes to digital.

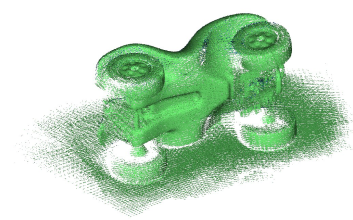
The starting point is where the affected body part of the patient is molded, mostly with regular casting plaster and I guess with a big mess. These moldings are kept and stored, which uses storage space.

Even this very essential and initial step can move on - into the glorious digital world. The solution is not very hard to guess...

3D Scanning!

3D scanning software

3D scanning is the process of analyzing a real-world object or environment to collect data of its shape. The collected data can then be used to construct or derive a usable virtual 3D model.
The 3D scanning process data output, are point clouds, a collection of arbitrary coordinate points in space which need to be oriented and aligned to a working coordination scheme.



Most 3D Scanner software is able to transform such point clouds into an open and unedited geometry type called mesh.

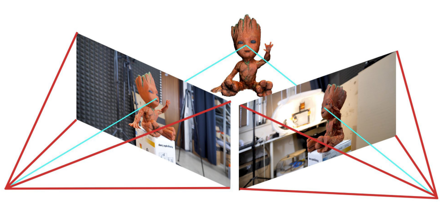
THE SOFTWARE

In the product development phase

There are different types of scanning technology available. Depending on the affected object and its environmental setting a specific technology is chosen. A 3D Scan-system will be delivered not only with the hardware, but also with a software that is capable of transforming the point into a mesh.

But there is a way to get a 3D scan without having scanner. Photogrammetry.

Photogrammetry literally means the act of deriving precise measurements from photographs. It involves taking a set of overlapping photos of an object, building, person, or environment, and converting them into a 3D model using a number of computer algorithms. That can even be performed with a smartphone.

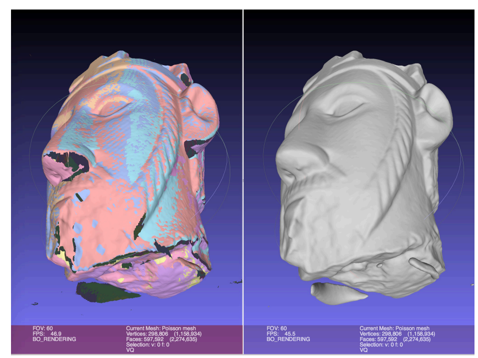


Photogrammetry software

- 3DF Zephyr
- Agisoft Metashape
- Autodesk ReCap
- COLMAP
- iWitness
- Meshroom
- Qlone
- RealityCapture

Mesh editing

Once an object is scanned and transformed into a mesh type, typically that mesh needs to be cleaned, fixed and oriented. Most scan software do not solve this problem. Another software that is capable of handling and editin such mesh-geometries must be used. This is where we have to start learning the science of meshes. Engineering 3D CAD works with Nurbs as a native geometry type. Nurbs and meshes can be compared to a 2D principle of vectors and pixels, whereas vectors are the Nurbs and pixels are meshes. As you might already know - when exporting a 3D model for printing is will also be transformed into a mesh geometry. The time has come where engineers and designers have to learn and know what a mesh is and how to edit it. Meshes are a hot topic in additive manufacturing. It is used not only for 3d scanning and printing but also to perform any FEM calculations. The established CAD software manufacturers, started to incorporate mesh tools, but for the time being on a very basic level with limited options. Typical processes are, filling holes, flipping triangles, removing noises, decimating and orienting in space. The image below shows a typical mesh from a 3D scan, before and after fixing.



THE SOFTWARE

In the product development phase

Mesh editing software

- Meshmixer
- Netfabb
- Magics
- Blender
- Meshlab

I recommend that you get yourself a free version of Meshmixer and play around with it. Even if you have no clue how it works, it is a very intuitive and playful way to acquire the first knowledge.

DESIGN AUTOMATION

Process automation is taking hold in several areas along the whole value chain. Known and implemented already in the manufacturing process itself, but there is still room to widen it out from end-to-end.
Bellow we will explain an automated design process for a part that needs to withstand a defined structural force but must be manufactured with the minimum amount of material. Reducing material, reduces print time, cost and of course weight, which benefits further factors.

Automation - Generative Design

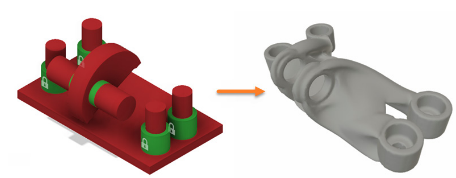
Generative design is a design exploration process. Designers or engineers enter design goals into the generative design software, along with parameters such as performance or spatial requirements, materials, manufacturing methods, and cost constraints. The software explores all the possible permutations of a solution, quickly generating design alternatives. It tests and learns from each iteration what works and what doesn't.

Simultaneous exploration: A notable benefit of generative design is that it allows the simultaneous exploration, validation, and comparison of hundreds or thousands of design options. The software can display and compare design options in a way that enables engineers to quickly and efficiently find the ones that best meet a project's parameters and needs.

Accelerated design time line: When engineers leverage AI to discover and test new complex design iterations quickly, efficiently, and at scale, they can drastically shorten research and development time lines for new products. As a result, companies utilizing generative design can gain a competitive edge in accelerating products' time to market.

Leverage advanced manufacturing processes: Generative design can create complex designs like organic features and internal lattices to leverage the unique design freedom offered by additive manufacturing technologies. It also offers the ability to consolidate parts, so a single complex geometry created by a generative algorithm and 3D printed can often replace assemblies of dozens of separate parts.

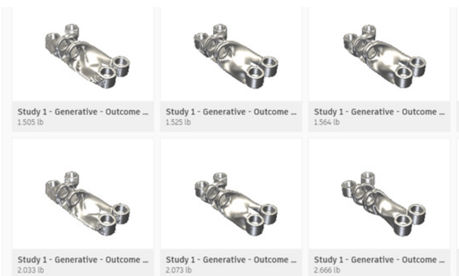
The image below shows the starting situation with loads and constraints in a CAD model automatically processes to the optimized part.

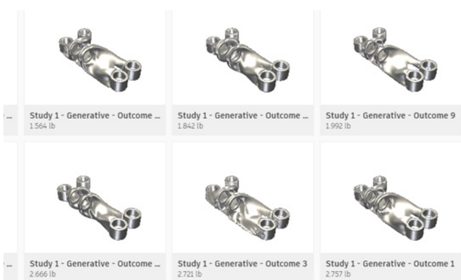


THE SOFTWARE

Design automation

The benefit is not only an optimized weight to strength ratio, but also a design process that does not require 3D modeling anymore. Its more like being a design author, that chooses from a set of generated designs or iterate the design further times.





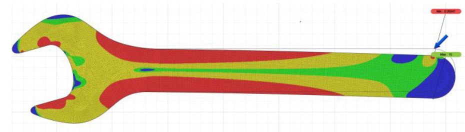
Generative design software

- Fusion 360
- Creo Generative Design
- nTop Platform
- NX from Siemens
- MSC Apex Generative Design

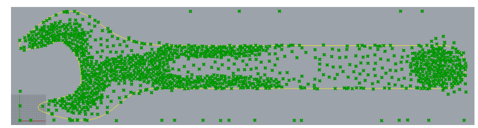
Rhino 3D Grasshopper

Another way to automate or mass customize parts and products, is the use of an algorithmic modeling process software. Grasshopper is a visual programming language and environment that runs within the Rhinoceros 3D computer-aided design application. The program was created by David Rutten at Robert McNeel & Associates. Programs are created by dragging and connecting algorithmic components onto a canvas. The images show a possible application based on the same idea of generative design. The starting point is our traditionally CAD modeled part, which undertakes a FEM calculation with a stress cumulation area shown as a typical gradient map. That gradient map will be fed into a Grasshopper setup and processed to a finished object.

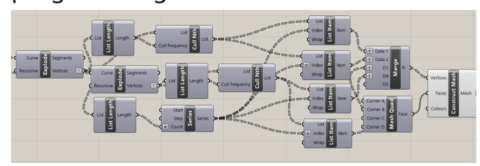
FEM calculated stress gradient map



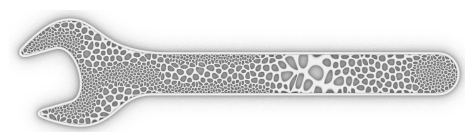
Point cumulation for geometry generation



Part of the whole algorithmic programming



Output geometry, ready for 3D printing



CAD AND CAE

CAD is the abbreviation for computer-aided design, which refers to using a computer to visualize a product idea. CAE is the abbreviation for computer-aided engineering, which is the analysis of the designed visualization. In short, the difference between CAD and CAE can be put this way: CAD is for designing a product and CAE is for testing and simulating it. Both play a key-function in the digital product development process.
We assume, that you and your company is already using CAD tools in some extent. Over the years trained and applied.

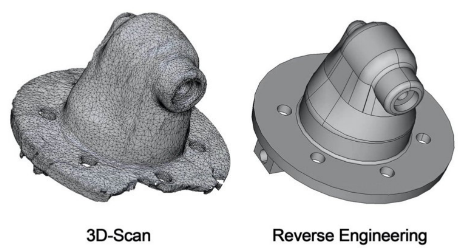
Why question what already works in a process?

Because with new technologies you are confronted with new tasks, processes and uncharted potential. An example is the previous shown design automation process, which i bet is something you never have actively done for your own products. Try it!
Here we will point out tools in CAD that are important for the process.

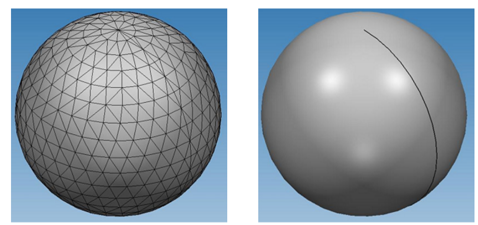
CAD and Reverse Engineering

3D Scanning opens up new product development capabilities and manufacturing processes. As described previously, the output data are meshes which cannot be edited in the traditional way and must be translated to Nurbs.
This translation process is called Reverse Engineering. That process needs a complete new set of tools, which are only available in specific CAD tools or via plug-in.

Typical 3D scan data of a damaged object which need to be digitally repaired and prepared for manufacturing.



A mesh normally consists of numerous planar triangles. The term planar need some special attention. For example a sphere in a CAD has two informations. The yxz coordinate center position and a radius value. Where as a mesh sphere is described with lots of planar triangles, thus not really a “sphere”. The amount of triangles, defines the resolution and detail of an object. Defining the degree of resolution has to be in balance between required detail and data size.

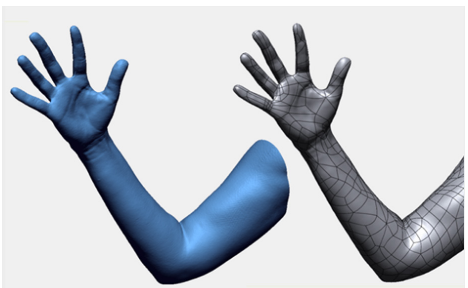


There are 3 main types of reverse engineering processes to interpret the mesh into a nurbs geometry. Depending of what is required and desired, a certain technique is applied. A source object that was originally manufactured with a milling process follows a different approach than a free-form body or car part.

3 Reverse Engineering approaches

Quad Re-mesh modeling

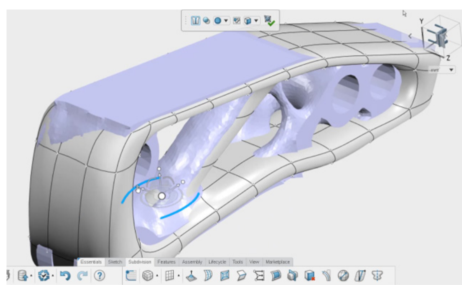
Nurbs surfaces always derive from 4 sided bounds. Even a nurbs triangle has 4 sides, whereas a triangle in a mesh is always planar and has 3 sides. It is required to interpret those two "languages" from something with 3 to something with 4 sides. Therefore the term quad. Professional software is able to perform a semi-automatic translation.



In the image you can clearly see the Quads. This new generated geometry is now based on the usual nurbs and can be edited in the traditional way. But any modeling features is not recognized.
A typical feature is for example a fillet or hole, both defined with a value. In quad re-mesh, the hole does not have a center nor a radius. It is just a hole.

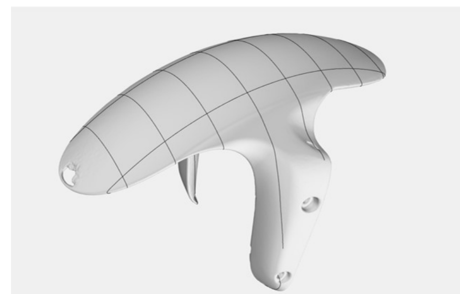
Sub division modeling

SubD, or sub division modeling, is a set of surfaces based on a cage of points. You can pull on the cage to change the shape of the surface. It's like a 3D equivalent of a spline, where you move control points. It also can bee seen as a mix both advantages of free-form polygon-modeling, known from game and animation software, and the precision and editability of nurbs. This approach is mainly used when only a section of the object needs to be modeled. For example when a prothesis is not only adapted to the arm/leg stump but also modeled the rest of the object.
For highly organic shapes it the most recommended approach. It provides great organic modeling capabilities, but still bases on nurbs.



Primitive and cross section modeling

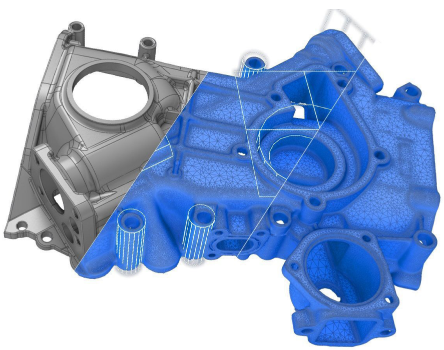
If quad re-mesh or SubD tools are not available in your CAD software, a manual reconstruction can be performed. Analyzing and building up the primitive geometry, such as cylinders, planes, holes and cubes is required to start with. The free-form surfaces will be reverse engineered, by cross sectioning the scan and build the nurbs geometry by using the traditional surface creation tools.



But as you might remember mesh is flat triangles, extracting line information from a scan, results in polylines. These are hundreds of short straight line sections, that need to be translated into a smooth spline to achieve a smooth surface.

Reverse Engineering software

- Geomagic Design X
- Catia
- Autodesk Fusion 360
- Siemens NX
- Ansys Spaceclaim
- Mesh2surface
- Rhino 3D



CAE
Simulating for additive manufacturing

An important factor for cost-efficient additive manufacturing is the use of simulation software. Since incorrect prints can quickly become critical for any budget because of expensive machine running times, it makes sense to use simulations during product development to identify the critical points of the component regarding the printing process. Waste can be avoided by early adjustments to the component design or the printing process. With simulation tools, it offers the user support in optimizing the design for additive manufacturing and ensures reduced development and production costs.
Such simulation and optimization processes include:

- Orientation
- Support structures
- Distortion (incl. Predistortion)
- Stress
- Export into layer data format

How do I determine the optimal process parameters for metal 3D printing?

Process parameters precisely matched to additive materials are the key to ideal 3D printing. Only the right combination of laser power, laser speed and hatch distance guarantees success. With the use of simulation software expensive investigations with prototypes can be minimized. Methods such as single bead, porosity, thermal history and micro structure prediction are used to determine and simulate optimal parameter combinations in advance.

Additive process simulation software

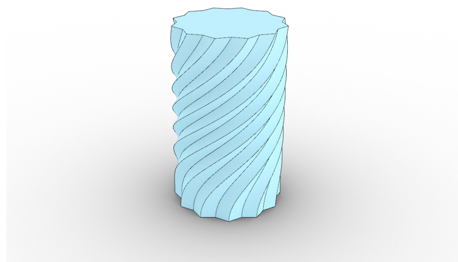
- Comsol
- 3DSIM - exaSIM
- Simulia
- Amphyon
- Sunata
- MSC Simufact

SLICING

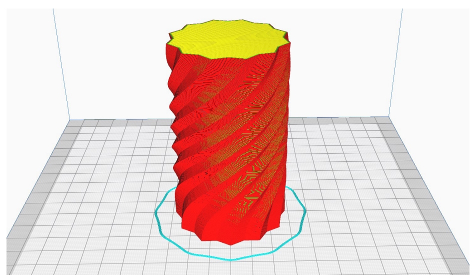
Preparing the model for 3D print

A slicer is a program that converts digital 3D models into printing instructions for a given 3D printer to build an object. In addition to the model itself, the instructions contain user-entered 3D printing parameters, such as layer height, speed, and support structure settings. A 3D printing slicer prepares the model for your 3D printer, generating G-code, which is a widely used numerical control (NC) programming language.
The input geometry is a "watertight" mesh, which is a closed and solid object. For optimal printing, there are numerous settings to be considered and defined. These parameter settings heavily depend on the final intention of the part. The 3d model is solid and it is not the intention of AM to print the whole solid volume. Basic definitions like, wall thickness, infill density and layer-height are starting definitions. These settings can be done by default parameters, but with some experience you will be able to get more efficient results, with custom settings.

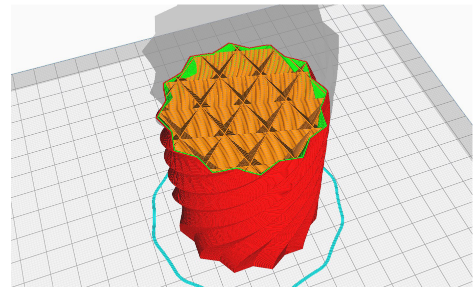
When buying a 3D printer, a slicing software is always included. They are similar among others, meaning once you know how to set parameters, you will be able to perform it on all other slicers.



A 3D object modeled in a common CAD software.



The same object with default silcer settings for an FDM/FFF print



The slicer software will "shell" the model and creates an infill, which has the function of reducing material and weight, thus printing time. These basic settings underlay the final usage of the print. If it is just a decorative object, infill can be on a minimum, whereas a structural part needs as much infill as to comply with the function. The best way to define such setting is by test-printing or with a CAE software. There are up to 1000 definable slicer settings, but usually you are safe by setting 10-20 parameters. Consider that each additive manufacturing technology follows a different slicing concept. Remember that SLS does not require support structure, but SLA/FDM/FFF does.

THE SOFTWARE

Try new tools

Slicing software

Any 3D printer will come with its own slicing software, but it is almost guaranteed, that an FDM/FF Printer slicer will be based on "Ultimaker Cura", eventually with a customized interface, but definitely with hardware pre-settings of the acquired machine.
For your own training and learnings, you can use a slicer without having a 3D printer. Download a free copy of Cura, play around with the settings and analyse the material usage and printing times.

Common FDM/FFF Slicer:

- Cura (free)
- Simplify3D
- Slic3r

WHY NOT APPLYING YOUR PRODUCT TO THE SOFTWARE?

Huh?
In design engineering, usually is the other way round!
We learned that CAD knowledge and capability should never dictate how a product will look like. The function and the manufacturing process on the other hand should do that.
The AI and computing power resources available can perform operations that creates the product for you. Basically it is entering requirements and performance of an object or part. Defining function, loads, restrictions and weight for example, and let the software do its magic. The software will define the design, the technology and the material for production and it will calculate the costs of the manufactured product. Not just one suggestions - thousands if you desire!

Exercise
Choose a product or part that you might see a potential for re-designing or re-development. Evaluate the whole development and manufacturing incl. up- and downstream processes and visualize the steps chronologically. Try to find the most ideal software for each step, by researching and testing. Once you have a promising layout, find out how these softwares can be networked and automated.
Let's say we start with an automated material replenishment for our 3D printer and end with the fully automated quality control or...
...the block chained circular economy cycle. You choose.

CHALLENGES

ADDRESSING YOUR DOUBTS

CHALLENGES

Technical Challenges

AM is mainly used for prototyping. But why is that? One of the reasons is surely that a lot of organizations and their engineers are still impeded by traditional design constraints. The further research required to overcome technical challenges is another reason for poor AM adoption in manufacturing companies. In order to push AM adoption beyond the purpose of prototyping, there are a number of technical challenges that need to be addressed, mainly in the area of materials and processing.

Material challenges

Materials for traditional manufacturing technologies have already undergone years of development in terms of both processability and necessary product properties. In addition to this solid data- base of materials, the industry has defined material standards and specifications through globally accepted and used norms. With AM being a rather young technology, there is still a gap to close in terms of development, standardization and qualification of materials. The economic success of AM technologies depends on the degree to which manufacturers can ensure that properties of the materials used to make the required shapes or structures actually meet the industry's predefined and accepted norms or standards. Currently, only a few materials can be processed within the required quality specifications, and there is still standardization necessary for those that can.

IT Integration Challenges

The entire process of customer-specific AM is largely manual today. In other words, a CAD model is designed, sliced for 3D printing and then transferred to the printer using a USB stick with the files. The process is monitored via a display on the 3D printer, while quality checks run manually after the print is completed. This is comparable to the manual steps often seen in the post-processing of 3D printed parts.
This manual labor is justifiable to some degree for early use cases of AM. In prototyping, with a limited number of parts produced and little need for extensive data collection, it was not necessary to closely integrate the 3D printer into supporting software solutions. Now that the application landscape is shifting towards mass production, it is becoming increasingly important to reduce costs for items such as manual labor through integration.

Design Challenges

What is the right approach?
In general, there are two possible approaches to start adapting to integrated AM. Most companies are trying to identify existing products that could move from conventional manufacturing to Additive Manufacturing. It is extremely difficult to generate a positive business case for serial production in these cases. While customer requirements naturally define the product features, the impact of the chosen manufacturing process on the product's design is not insignificant. There are different design principles for milling, molding, welding, etc. That define the form, look and feel of a product. Designers and engineers have to consider, for example, the minimum wall thickness and rounded edges for molding. Over the years, product design has been adapted and optimized

according to design principles of different manufacturing processes. Simply reproducing the product with AM is not efficient.
What are the design principles?
When it comes to AM, engineers still consider the same design constraints that complicate conventional manufacturing. Rather than shifting to an entirely new approach to design, they revert to comfortable design paradigms – especially engineers who may have spent much of their careers working through a conventional set of processes. In conventional manufacturing, there are clear roles for each stage of design and production. There are individualized tasks and extended design work flows for specialized tasks, each with multiple iterations for various design constraints. The design is modified for each discipline based on its given function.
The second approach rethinks the entire product structure in order to take full advantage of AM's capabilities. The challenge is to identify the part and assembly designs determined by the current manufacturing technology and consider whether AM can improve performance.

Capability Challenges

A successful adaption to AM will require new engineering and management skills to exploit the full benefits of this technology, although we are currently facing a significant skills gap. It is difficult to find well-trained and skilled workforce that are capable of applying 3D printing to real-world production. Even though current engineering graduates may have learned about the technology, it is unusual to find potential recruits who understand the holistic capabilities of the technology. Additive Manufacturing is not a technology for specialist technicians like welding, for example, but rather a field for generalists able to combine such different disciplines as mechanical, fluid and material engineering. As a result, most of the workforce is still too unfamiliar with the different materials and the requirements of the design process to take full advantage of the potential offered by AM. The current shortage of talent calls for new education initiatives to deliver a skilled, capable and adaptable workforce. However, without any norms or standards for AM design principles, the industry has been unable to establish uniform apprenticeships or study programs.

Financial Challenges

Identifying the business case of disruptive technologies is a significant challenge as well. When we think back to the launch of the first iPhone, we understand that it changed the game not because of its initial technology. Top-line phones from other companies had more memory, better cameras and faster mobile connectivity. The business case was rather the result of the full extent of the product.
In general, the cost factors for conventional manufacturing relate to machines, materials, equipment, tooling, labor and overheads such as energy and space. For Additive Manufacturing, the cost model is structured as a series of work-flow steps: preparation, printing and post-processing, where each step has its own cost factors. These factors are different than those of conventional methods. There are usually no investments needed for mold tooling and the equipment can be used for a variety of purposes.

READINESS MILESTONES

Get ready for the next level

It would make less to no sense defining clear milestones that must be achieved during this general additive manufacturing knowledge acquisition. AM has such a widespread application range that for each application field, different readiness milestones must be stated. But you can call yourself generally ready for the next chapter in this book by being able to “Elevator Pitch” the following questions:

1. What is additive manufacturing?

2. How does additive manufacturing work?

3. Why use additive manufacturing?

4. Is additive manufacturing expensive?

5. Does it require special software?

5. What will be major challenges?

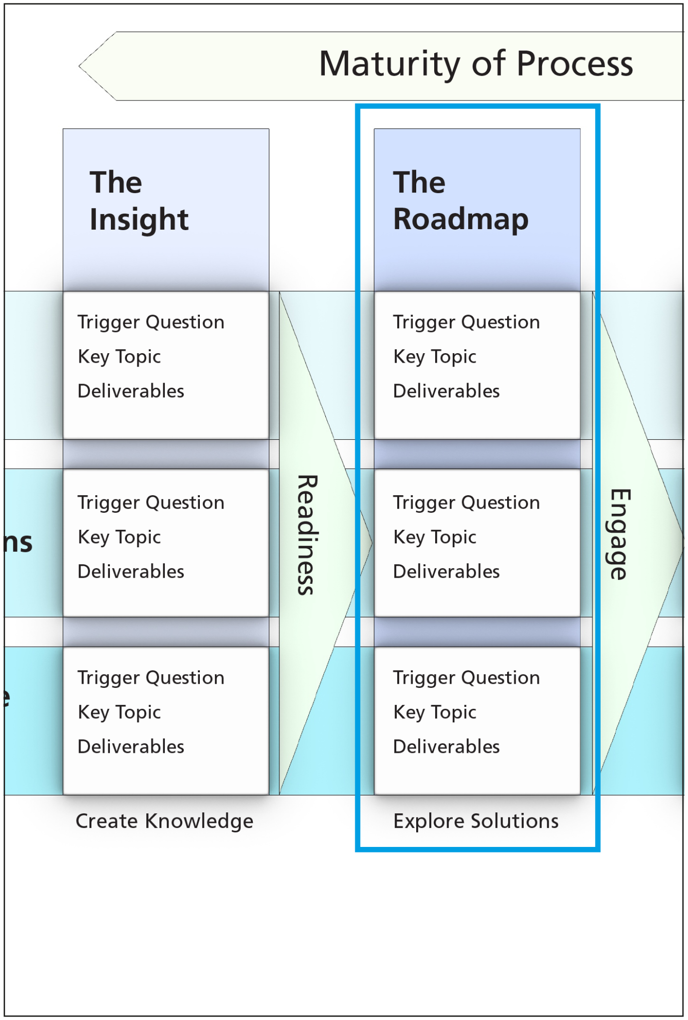
6. What are common materials used?

KNOWLEDGE LEVEL 2 “THE ROADMAP”

Let’s sort out the right puzzle pieces and arrange them for the success plan

COLUMN "THE ROADMAP"

Goal: Able to create a roadmap



ENGINEER POINT OF VIEW

Trigger Questions

Which application brings value in AM?

What are the advantages compared to traditional manufacturing?

What equipment do I need?

Key Topic

Identify and understand the key benefits of AM

Unleash creativity and find innovative AM applications

Design rules for AM

Screen and select parts from the product portfolio

Deliverables

AM possibilities and limitations, applied to portfolio

Potential AM parts list

Redesign of the first AM part

Hard- and software shopping list

COLUMN "THE ROADMAP"

Goal: Able to create a roadmap

OPERATIONS POINT OF VIEW

Trigger Question

What's the impact of AM to our process organization?
How to educate employees?
What drives cost?

Key Topic

Identify and understand the key benefits of AM
AM employee requirements
Cost structures of various approaches
Adaption time-line

Deliverables

Business Case
Employee recruitment concept
Feasibility studies
Investment impacts

EXECUTIVE POINT OF VIEW

Trigger Question

What's the impact of AM to our organization?
Is AM financially feasible?
What drives efficiency?

Key Topic

Comparison of different production scenarios
Base for strategic decision-making
Stay ahead of your competition
Cost and Investments

Deliverables

Business case for selected applications
Knowledge management strategy
Evaluation of new business models
First Roadmap draft

USE CASE 1

From global supply chain disruption to local production

KELVA®

Company

KELVA is the world's leading supplier of web and sheet cleaning solutions for the treatment and processing of materials such as paper, corrugated board, fabrics, non-wovens, films or glass, removing the smallest particles, dust, fibers and other foreign matter without stopping the production processes.

Situation

The sudden supply chain disruption caused by the pandemic situation, resulted in unavailability of an essential component for the system. The affected part is an air-box connector for compressed air and vacuum. This situation led to the inability to deliver a complete system. KELVA was not able to sell and therefore did not create any revenues. The clients needing this system, were forced to switch the manufacturer.

The company was forced to find a quick and sustainable solution, to continue delivering the cleaning systems. The risks of global supply processes became abundantly clear during the Corona crisis. Therefore, it had to be evaluated to what extent additive manufacturing could be used to produce components, especially the affected component itself.

Solution Exploration

In this specific case, an analysis was required of the extent to which certain parts of an industrial plant manufactured using the traditional process could be replaced by 3D-printed components. An additive manufacturing consultation was therefore required, which on the one hand required clarifications in terms of technology, material properties and design, and on the other hand also had to include business management considerations. Following by material and print tests, checking the possibilities in post-processing and optimizing the composition of the 3D printed parts with the existing components. A simple transfer of the existing CAD files was out of the question from the beginning, since other parameters have to be taken into account with the additive manufacturing process. The existing assembly had previously been produced using the classic sheet metal forming process. The change of the manufacturing process also required a change of the material and the component design.

Process and part optimization

During the analysis process, it became apparent from the CAD data that various optimizations could be made in the component. For example, the assembly could be merged into a single part, which makes assembling obsolete. In addition, the optimization of the component resulted in an improved air flow and a reduction in weight. It became very clear that an in-house 3D printing environment would be worthwhile the investment and a good degree of supply chain independence will be gained.

USE CASE 1

Least painful shift to AM by changing the manufacturing of just one component!

Added value in the final part

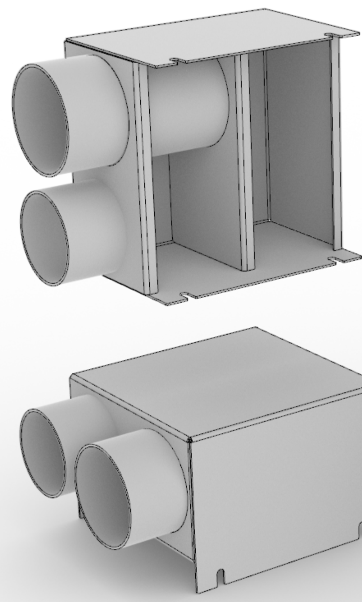
- No assembling
- No welding
- No powder coating
- Haptic 3D logo
- Optimized air flow
- Added support surface for gasket
- Local and on-demand 3D printing
- No stock management
- Customized variants
- Cost reduction

Conclusion

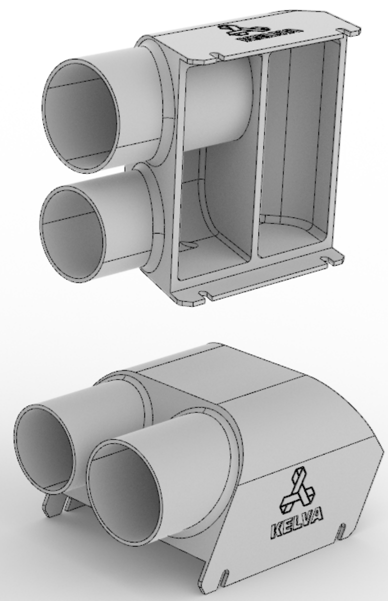
The trigger to transform production to additive manufacturing, evolved from a incisive supply chain disruption of only one component. The unsuspected value gain by using a different manufacturing technology for that component was immense.

Remodeling the component for AM production and buying a 3D Printer for 15k CHF was basically the only thing to be done for a successful step towards additive manufacturing.

Original air box part



Redesigned air box part



USE CASE 2

Customized 1-off car body panels

REVERSE CUSTOM

Company

Designunity, a design studio based in Zürich, develops product and design concepts for companies from a wide range of business sectors. Under the name "Reverse- Custom", the company develops various individualized one-off products for the automotive and aircraft industries.

Situation

The established design studio wanted to offer individual parts for vehicles and aircrafts with a new idea. To do this, the company was looking for a way to digitally capture and edit these individual parts. In a further step, these models were then to be produced using additive manufacturing. The company has solid CAD and AM knowledge and needed further advice in the area of reverse engineering. At the same time, the finished parts had to comply with the Road Traffic Law (SVG).

Solution Exploration

An important component of the solution was a suitable 3D scanner. Various 3D scanners had to be evaluated and then various scan tests carried out on vehicles. In a second step, Road Traffic Law (SVG) compliant materials and printing technologies were researched. Strict specifications must be met on all parts for use on the road or in the air. In order to expand the existing knowledge in the areas of 3D scanning and reverse engineering, an individual training course was conducted. The company is now able to scan vehicles itself and prepare them for 3D printing. Using the inexpensive and uncomplicated 3D printing technology - FDM /FFF - it is possible to prototype the newly designed parts before printing the final part using the expensive technology.

Customizing on a new level

For the company, the application of new technologies resulted in several advantages. Thanks to additive manufacturing, the company can now produce individual parts in small quantities. The entire process up to the production of the parts has been digitized, resulting in savings of time and resources. The company's customers also benefit from the digitization of the process. The desired design can now be examined together with the customer, live on the FDM/FFF printed prototype and virtually adjusted on the CAD.

Conclusion

The trigger using new technologies to start a new business model, came from the desire to be able to produce one-off products. In the customizing business there is always only one.
Adjacent businesses could be the recreation of missing oldtimer parts.

3D Scanning and processing the data with reverse engineering was not the trickiest part. Finding a technology and material that is certifiable and complies with the road traffic law, was never done before and required some patience for the authority.

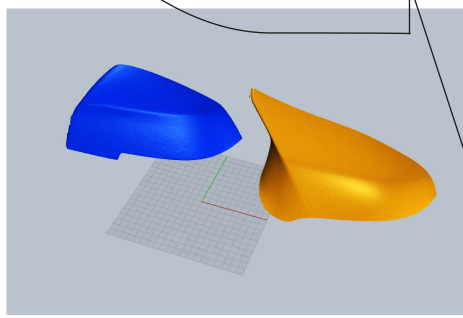
USE CASE 2

No tooling, minimum lot size, warehouse or extended logistics required

Retro-fitting a BMW M4 side view mirror on other models

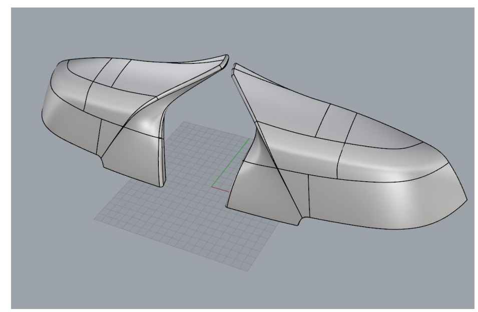
Original BMW M4 side view mirror

Other BMW model side view mirror



3D scans of both models. Reverse engineered to have the look of the M4, but fitting other BMW models.

SLS 3D printed final product in PA12 and painted



CAD model, which is digitally warehoused and printed on demand

USE CASE 3

Customized concrete form-works

Company

The company was founded in 1923 by Wilhelm Geiger as a timber trading and haulage company. It is now run by the fourth generation
In the 1930s, Geiger began mining gravel and built gravel plants in Betzigau and Sonthofen, Germany after World War II. In the 1970s, Geiger developed into a construction company. In 2008, the subsidiary Geiger Building Restoration was founded.
NOWlab, a Berlin based Design Studio was able to accompany Geiger in this transformation to AM, with their design and process knowledge.

Situation

For the conversion of a disused brewery into office space and event rooms, large stone window arches had to be replaced under a tight schedule, while maintaining the impressive original aesthetics of the structure. Also, no CAD data was available for the production of the concrete molds and there was varying warpage of the individual arches. There were two options for the contractor. One was the traditional solution, which requires a high level of expertise and is time-consuming and cost-intensive, or a new method using 3D printing.

Solution Exploration

A handheld scanner was used to scan the different window arches and the data was loaded into a suitable CAD program. Using this CAD data, 3D models of the negative shape of the window frames were created. Subsequently, the casting molds were printed using an FDM /FFF 3D printer with biodegradable PLA filament.

Savings and Sustainability

Geiger estimates the elements developed and produced with 3D printing and scanning, cost 50% less than they would have from a stonemason, with a production time shorter than 45% compared to a resin-foam cast production. Geiger was also able to considerably reduce staff resources needed for the project. Combined with a high-quality finish, this was the perfect solution for Geiger.

Conclusion

Over time it seems probable that Geiger and others will increasingly adopt these methods in their renovations. However, reconstruction is only one way to apply the basic technique.
The creation of both architectural facades and load-bearing, structural elements are prospect possibilities.
The advantages of production speed, reduced cost, and environmental friendliness apply similarly to these applications. However with new products, the flexibility of the print process unlocks huge design potential. We can expect elaborate new surface textures, exterior forms and structural characteristics in designs freed from existing constraints.
In this way 3D print based concrete casting offers a vision for the future of construction.

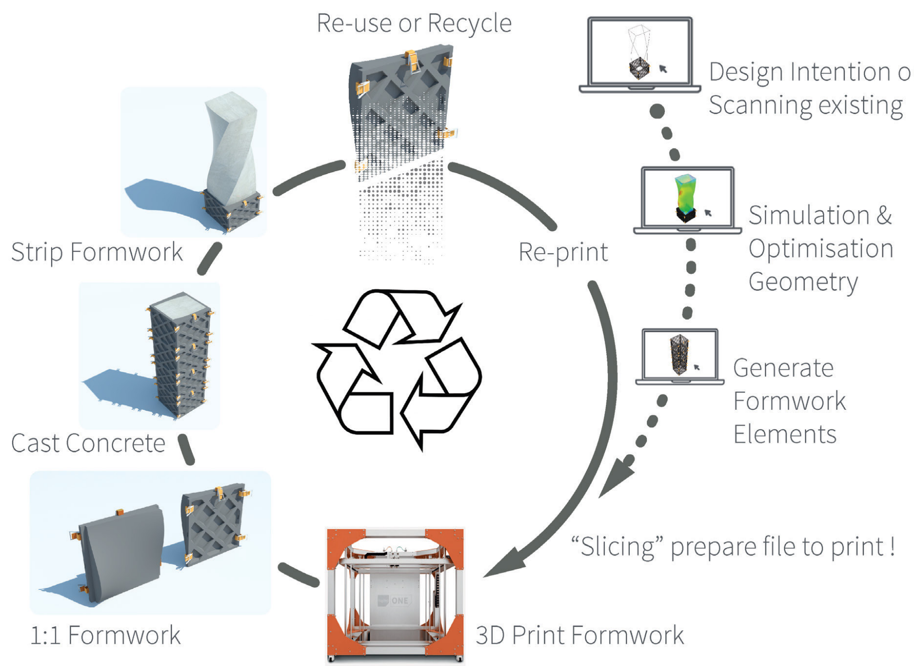
USE CASE 3

Fast custom concrete

Casting custom concrete elements for historical restorations

On-site casted window arc concrete part

Perfectly fits the warped building



Circular and sustainable process cycle

DESIGN FOR AM (DfAM)

Exploring new degrees of design freedom and apply value

Correct AM technology

Key principles for design for additive manufacturing is design for the correct additive manufacturing process. This is important as there are many different categories of additive manufacturing. To be able to design for the correct additive manufacturing process, you need to have a good understanding of the strengths and weaknesses of the majority of the additive manufacturing processes and match these to the geometry of the parts that are creating.

Minimal material usage

Design for additive manufacturing is design for minimal material usage. Often in additive manufacturing, we think that minimal material usage is only useful in industries that require lightweight components. However, material usage in additive manufacturing is also correlated to the build time and the cost of the print.

Improved parts functionality

Using options like part customization, internal fluid channels for heating or cooling, added surface texturing to parts. All of these methods extend additive manufacturing from an alternative method of producing a part to the only method of producing a part.

Topology optimization

Topology optimization is a type of structural optimization technique which can optimize material layout within a given design space. Compared to other typical structural optimization techniques, such as size optimization or shape optimization, topology optimization can update both shape and topology of a part. However, the complex optimized shapes obtained from topology optimization are always difficult to handle. To solve this issue, additive manufacturing processes can be applied to fabricate topology optimization result. However, it should be noticed, some manufacturing constraints such as minimal feature size also need to be considered during the topology optimization process.

Multi-scale structure design

Due to the unique capabilities of AM processes, parts with multi-scale complexities can be realized. This provides a great design freedom for designers to use cellular structures or lattice structures on micro or meso-scales for the preferred properties. For example, in the aerospace field, lattice structures fabricated by AM process can be used for weight reduction. In the bio-medical field, bio-implant made of lattice or cellular structures can enhance osseointegration.

Multi-material design

Parts with multi-material or complex material distribution can be achieved by additive manufacturing processes. To help designers to take use of this advantage, several design and simulation methods has been proposed to support design a part with multiple materials or Functionally Graded Materials . These design methods also bring a challenge to traditional CAD system. Most of them can only deal with homogeneous materials now.

Design for mass customization

Since additive manufacturing can directly fabricate parts from products' digital model, it significantly reduces the cost and leading time of producing customized products. Thus, how to rapidly generate customized parts becomes a

DESIGN FOR AM (DfAM)

Exploring new degrees of design freedom and apply value

central issue for mass customization. Several design methods have been proposed to help designers or users to obtain the customized product in an easy way. These methods or tools can also be considered as the DfAM methods.

Parts consolidation

Due to the constraints of traditional manufacturing methods, some complex components are usually separated into several parts for the ease of manufacturing as well as assembly. This situation has been changed by the using of additive manufacturing technologies. Some case studies have been done to show some parts in the original design and can be consolidated into one complex part and fabricated by additive manufacturing processes. This redesigning process can be called as parts consolidation. The research shows parts consolidation will not only reduce part count, it can also improve the product functional performance.

Lattice structures

Lattice structures is a type of cellular structures. These structures were previously difficult to manufacture, hence was not widely used. Thanks to the free-form manufacturing capability of additive manufacturing technology, it is now possible to design and manufacture complex forms. Lattice structures have high strength and low mass mechanical properties and multi functionality. These structures can be found in parts in the aerospace and biomedical industries. It has been observed that these lattice structures mimic atomic crystal lattice, where the nodes and struts represent atoms and atomic bonds, respectively, and termed as meta-crystals.

Thermal issues in design

For AM processes that use heat to fuse powder or feedstock, process consistency and part quality are strongly influenced by the temperature history inside the part during manufacture, especially for metal AM. Thermal modeling can be used to inform part design and the choice of process parameters for manufacture, in place of expensive empirical testing.

Minimize overhangs

Each successive slice of your part as it is printing relies on the layers below it for support. Large overhangs, openings and other features may require additional support during the build to prevent warping and ensure the product achieves its performance tolerances. Parts designed with DFAM principles in mind will be self-supporting, minimizing the need for supporting features which can add cost through material waste and added post-processing needs. And if supports are required, one cost-saving consideration would be to orient the part so that supports are placed in regions that aren’t user-facing, where marks are acceptable. This reduces the sanding and finishing time required in post-processing.

Part orientation

While additive manufactured parts can be built in many orientations, the angle at which a feature is built can affect its tolerances and part strength. And because features can only deviate from the spec so much until it affects tolerance limits, it’s important to consider a range of possible orientations early on in the design process. That way, you can identify which orientation is best-suited for producing your part.

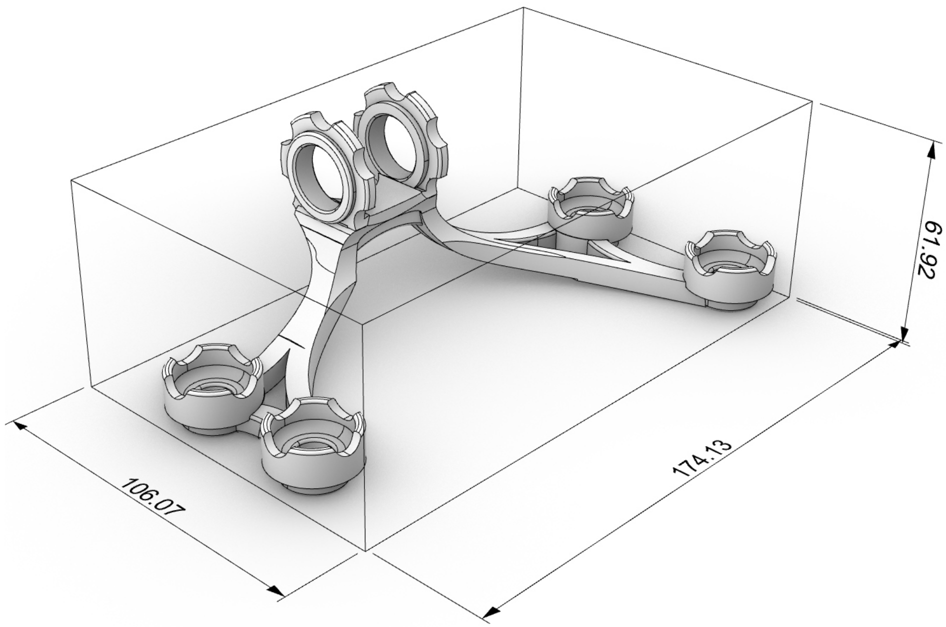
COMPARING PARTS COSTS

Just a quick shot to have a feeling for printing costs

Comparing production costs

Of course, the total cost of a manufactured part depends on many factors. In this example, the idea is to give you just some "about" costs. The starting point is a "traditionally" designed mounting bracket, intended to be manufactured with CNC machining and no post-processing. The material of the calculated parts, is not available for all technologies. The most wide-spread material for each technology was chosen. Batch size of 10 parts.
As you learned in this book so far, it heavily depends on AM design engineering know-how. If you just take 3D data form a part that was constructed to be CNC machined, you definitely did not get the maximum efficiency for AM.

There are many Online platforms to get your parts manufactured, mostly for additive manufacturing, but some offer traditional processes, like CNC, Injection molding, Sheet Metal bending and turning.
It is recommended to start using those platforms for testing and validating your own intention and products. Not that you buy a 100k machine and find out that another system would have been cheaper and more suitable.



Sample Part of a mounting bracket, produceable with any AM or traditional manufacturing technology
Batch Size 10
Various Materials

COMPARING PARTS COSTS

COMPARISON		MATERIAL (DEPENDENT TO PROCESS)	PRICE PER PART BATCH OF 10	LEAD TIME FROM ORDER TO SHIPPING IN DAYS
CNC Machined		Stainless Steel 303	720 € -930 €	10 - 13
CNC Machined		ABS	510 € - 640 €	9 - 12

3D PRINTING TECHNOLOGY

Binder Jet	BJ	Metal 420i (Stainless Steel Infiltrated with Bronze)	280 € - 390 €	5-6
Direct Metal Laser Sintering	DMLS	Stainless Steel 316L	500 € - 650 €	5-6
Fused Deposition Modeling	FDM (100% Infill)	ABS	42 € - 50 €	4-5
Fused Deposition Modeling	FDM (20% Infill)	ABS	33 € - 37 €	3-4
Multi Jet Fusion	MJF	Nylon 12 / PA12	81 € - 97 €	3-4
Stereolithography	SLA	ABS - like	72 € - 81 €	3-4
Selective Laser Sintering	SLS	Nylon 12 / PA12	38 € - 45 €	2-4

COMPARING PARTS COSTS

Selective Laser Sintering - Time, Capacity and Parts Cost

Electrical Connector

Indeed, it is possible to move in to mass production with 3D Printing.
The most promising printing technology for such intention is Selective Laser Sintering.
Price calculation of course depends on multiple factors. This example part here only reflects the cost of the printing powder.

System used:
Sinterit Lisa X
Galvano Laser Technology

Machine Price:
17’000 €

Build envelope:
130mm x 180mm x 330mm

Material used:
Nylon 12 / PA12

Part Type:
Electrical Connector
End Use Part

Part Dimension:
22.5mm x 18 mm x 37 mm

Printed End Use Part

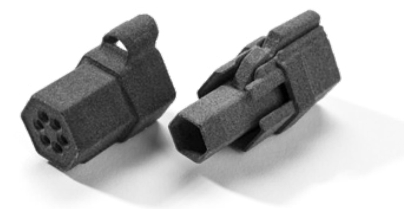
Material Cost per Part:
0.60 €

Total Printing Time:
28h (2min/piece)

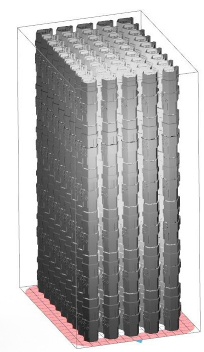
Total Batch count:
540 pieces

Further factors to take into consideration for a total cost and comparison calculation:
(Costs and/or Savings list non exhaustive)

- Machine
- Running costs
- Operator
- Tooling
- Lead-times
- Logistics
- Warehousing
- Maintenance
- Downtimes
- Shadow-printing
- Product Adjustments



Printed connector end use part



Sinterit Lisa X SLS Printer

Build Envelope with 540 pieces

COMPARING PARTS COSTS

Pellet Extrusion Robot System - High throughput

Housing component

Continuous production is possible with a pellet extruder attached to an industrial robotic arm, printing the parts on a conveyor system. The technology follows the FDM /FFF principles. The conveyor moves the finished part away, for the next print to start. The printing pellets can be replenished with a hose and air system.

System used:
Yizumi SpaceA
Pellet Extrusion Robot System

Machine Price:
75’000 € (fixed platform)

Build envelope:
640mm x 400mm x 900mm

Material used:
Nylon 6 Carbon Fiber 30 / PA 6 CF 30

Part Type:
Housing
End Use Part

Part Dimension:
190 mm x 150 mm x 200 mm

Part Weight:
190g

Part Printing Time:
31 minutes

Part Material Cost:
1.00 €

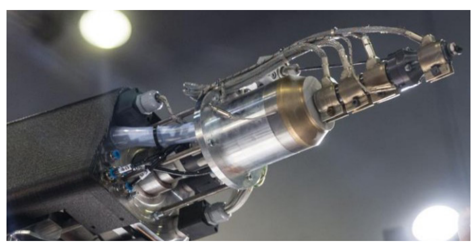
Machine Price:
75’000 €

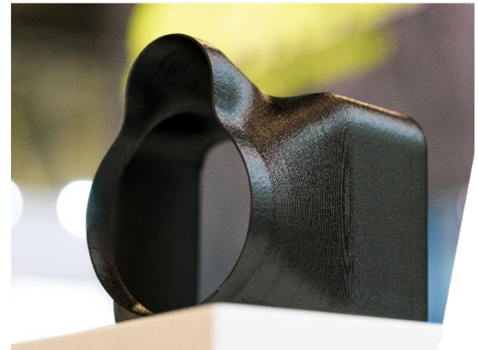
Annual Machine Running Time:
5000h

Annual Batch count:
9’500 pieces

Total Cost per Part:
2.85 €

Again, further factors have be taken into consideration for a total cost and comparison calculation.





Printed housing part

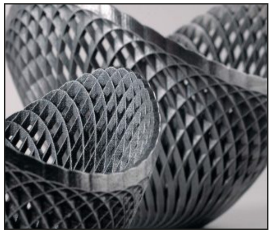
Yizumi SpaceA with conveyor system

SKILLS NEEDED

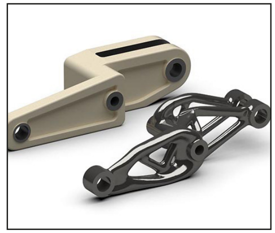
New Technology needs not only a new mindset but also new skills

Order Management

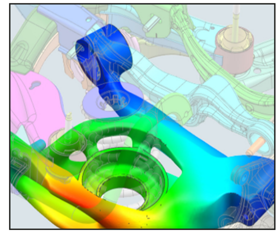
Design for AM



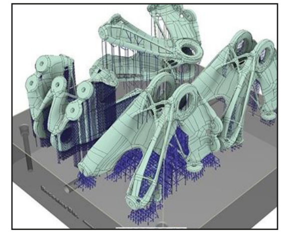
Generative Engineering



Design Validation

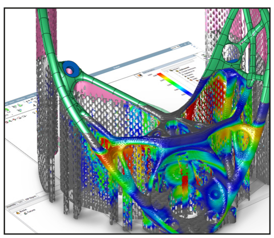


Build Preparation

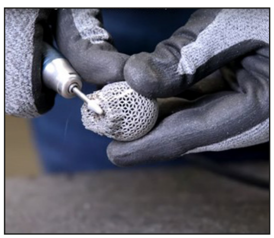


PROCUREMENT → **PRODUCT DEVELOPMENT** →

Build Simulation

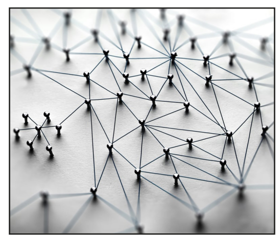


Post Processing

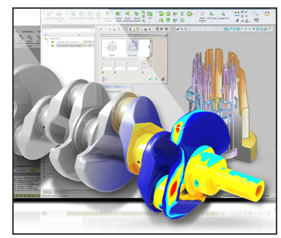


Scheduling and Execution

Machine Connectivity



Quality & Analytics



MANUFACTURING PLANNING → **PRODUCTION** →

SKILLS NEEDED

Skills along the process

Key Skills for Additive Manufacturing

The knowledge needed ranges from basic understanding of the technology to selecting components for production, as well as design and engineering, to scaling and validating production.

Understanding 3D Technologies

In additive manufacturing you need a comprehensive overview of the stages of the process chain and the different technologies.

Design and Simulation

Design is one of the most important parts of the additive manufacturing process chain. Without good design, every other stage is unpredictable. Designing 3D printed parts for real world use requires an in-depth knowledge of methodologies and guidelines and the possibilities and limitations in 3D printing, and how to apply this knowledge to design viable and innovative parts.

Application Engineering

To create a great application, you need to master both systems and software. To select the right quality part parameters for each case, you need knowledge about process parameters. Proper part screening and selection are highly important. You need the skill set to decide, which part fits best economically and technically to grant AM success and profitability.

Process and Materials

Each material has its unique properties and will behave differently in the process. Therefore, you need material specific parameter editor training to understand the values and the implications for data preparation. At the same time, you need to study the attributes of different materials and decide which material is best for which job.

Machine Operation

Before you can operate a system, you need training on the safe and efficient operation of the machine itself and its peripherals.

Post-processing and Surface Finishing

Additive manufacturing is not only about designing and preparing your project for 3D printing. A distinguishing professional feature is the level of post-processing skills needed to make realistic and accurate model representations. Therefore, you need to know about different methods and technology

Quality Assurance

Recognize the definition of quality within the 3D printing industry and how to measure it during each stage of the process. You need to learn about quality criteria such as dimensional accuracy, tensile strength, hardness, density, and electrical conductivity.

Developing skills for business

You need to learn how to properly carry out a business case analysis. This will be the moment to integrate your knowledge of the entire process chain. Get to know the impact of key cost levers and how to reduce overall cost-per-part. You need to understand both, the quantitative and qualitative side of the different types of business models and how to explain these to the many different stakeholders involved.

Distributed Production

Before you start serial production, you should simulate your production using a digital twin. As a result, you can forecast the throughput and output of your production site based on the machine park equipment, operator shifts, machine maintenance procedures, etc.
Since the entire process chain from procurement to production is digitally synchronized and all machines are connected and communicate via IIoT platforms, you can easily align your production with local demands while significantly reducing transportation and storage costs. By distributed manufacturing, we mean globally distributed small and flexible production centers that produce where the customers are and where the demand arises.

ROADMAPPING

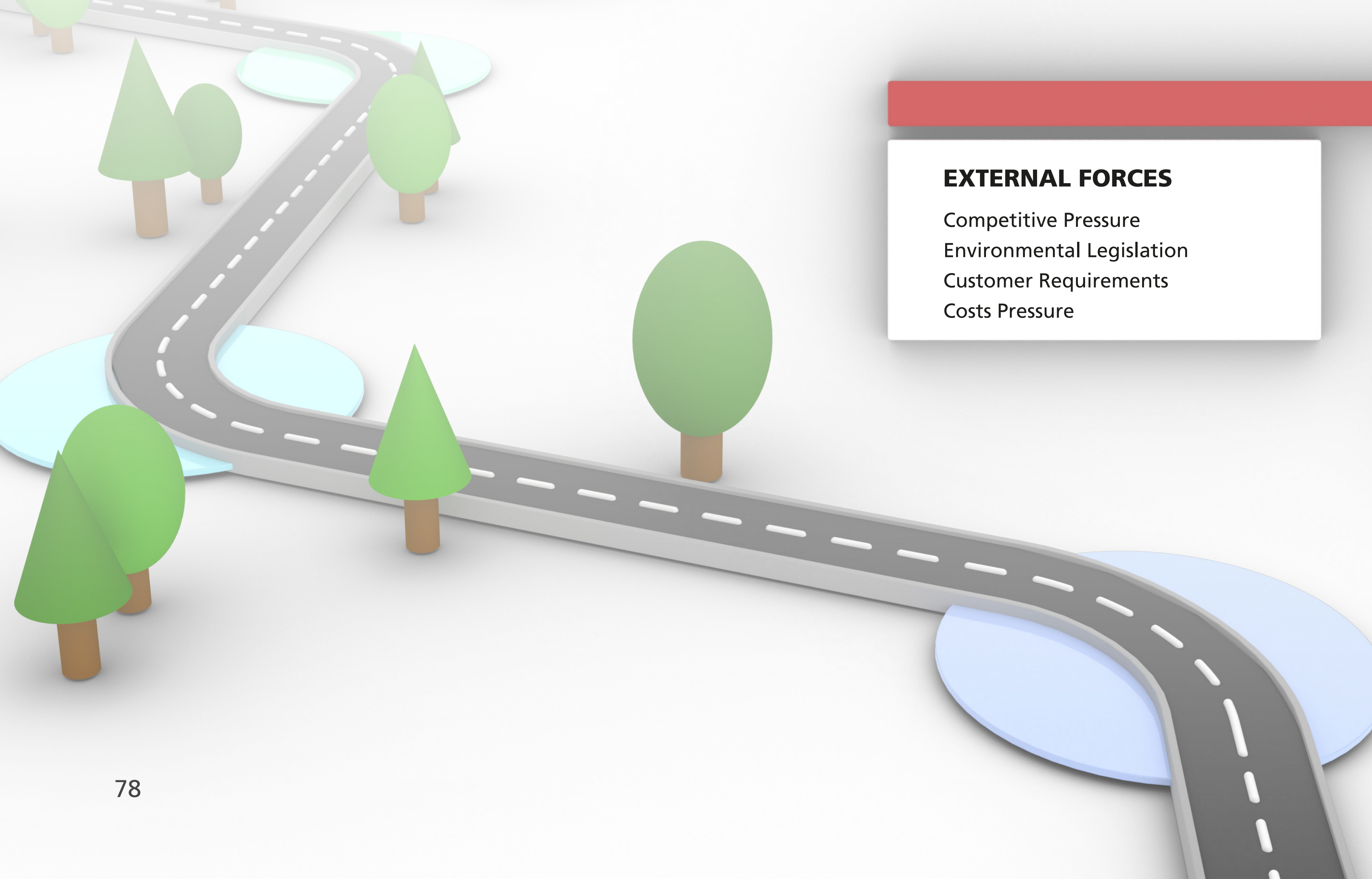
FRAMING THE SCOPE

Each intention for each business have a very specific road-map, which is hardly to define with a general layout, valid for a broad range.

The next pages will give some reference and inspiration how you could plot out your own AM-Travelmap.

DRAFT A SCHEME

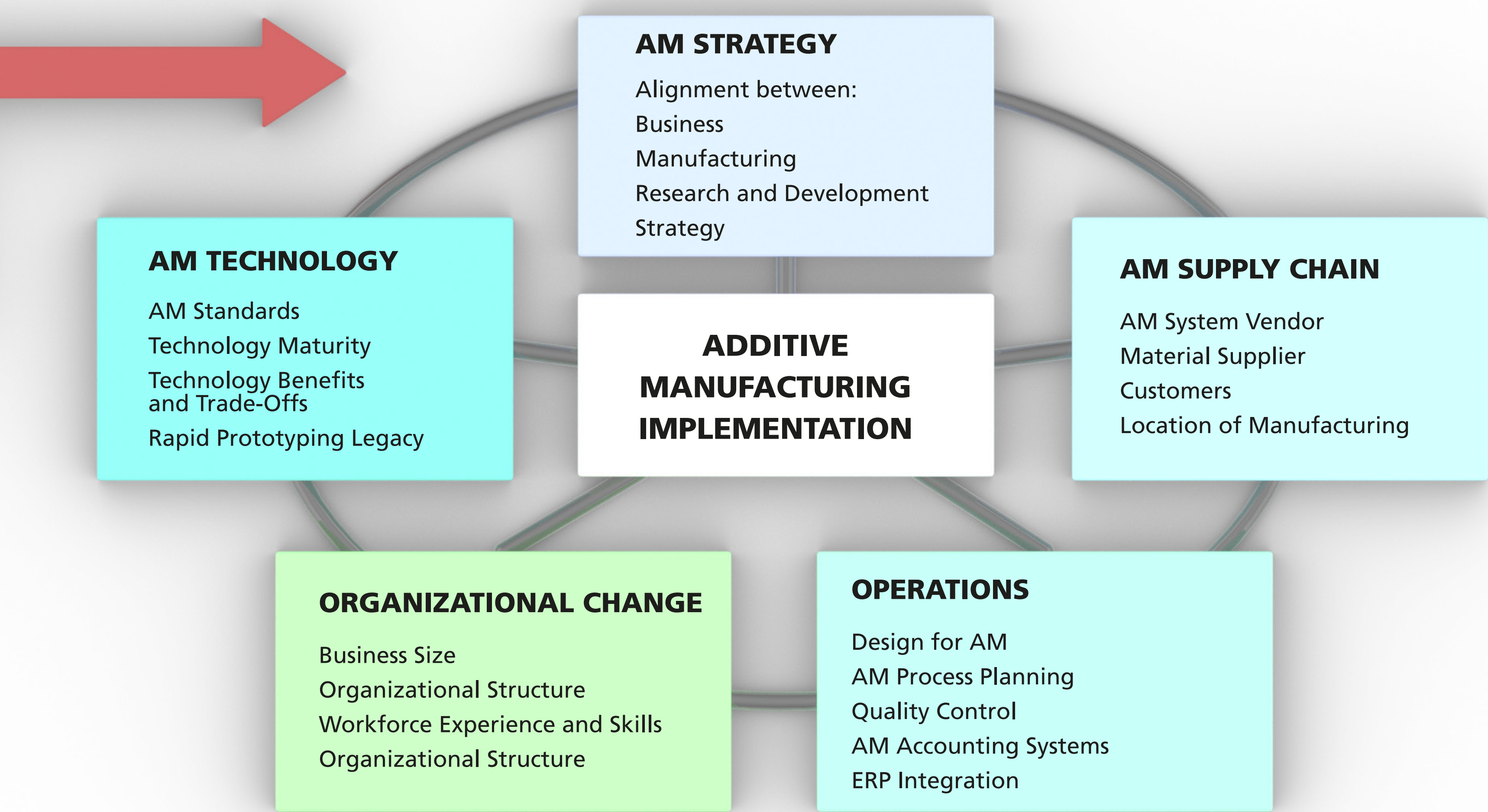
Sketching out a scheme - First rough concepts for a good overview of the scope.



EXTERNAL FORCES

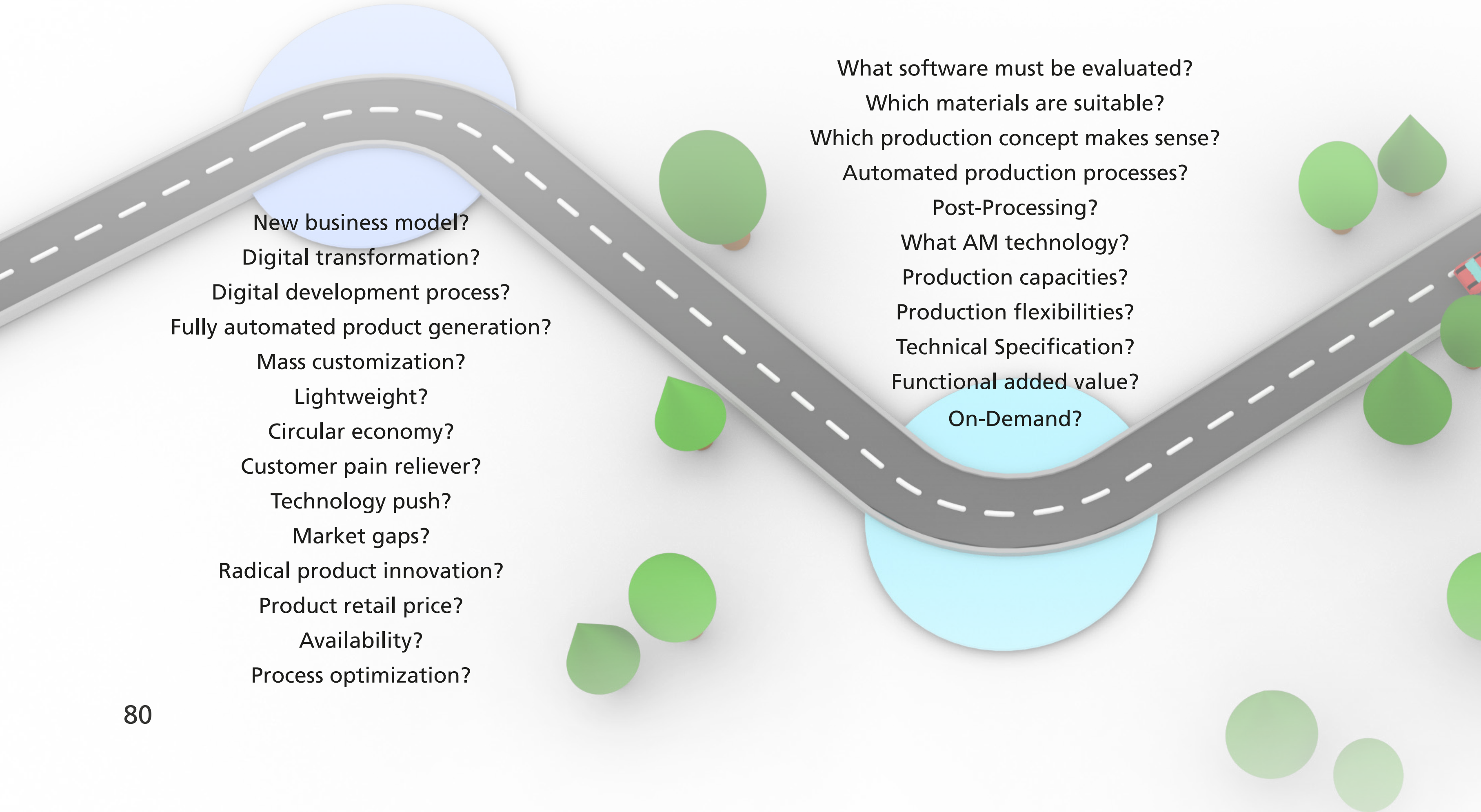
Competitive Pressure
Environmental Legislation
Customer Requirements
Costs Pressure

DRAFT A SCHEME



ANOTHER MAPPING APPROACH

Sketching out a roadmap - First rough concepts for a good overview of the scope.



PRODUCT OR BUSINESS IDEA

Why are you moving towards AM?

New business model?
Digital transformation?
Digital development process?
Fully automated product generation?
Mass customization?
Lightweight?
Circular economy?
Customer pain reliever?
Technology push?
Market gaps?
Radical product innovation?
Product retail price?
Availability?
Process optimization?

MANUFACTURING

How does it affect manufacturing?

What software must be evaluated?
Which materials are suitable?
Which production concept makes sense?
Automated production processes?
Post-Processing?
What AM technology?
Production capacities?
Production flexibilities?
Technical Specification?
Functional added value?
On-Demand?

ANOTHER MAPPING APPROACH

Visualize your journey

EXECUTION
What are topics to reconfigure

Post-Processing?
What AM technology?
Production capacities?
Production flexibilities?
Technical Specification?
Added value process?
What software must be evaluated?
Which materials are suitable?
Which production concept makes sense?
Automated production processes?

CONTROL AND MONITOR
How to monitor and control

Supply Chain Setup?
Product distribution?
Production scale?
Quality assurance?
Digital processes?
Warehousing?
Continuous improvement?
Technology upgrades?
Block chain?
Stakeholders?

FOCUS ON TECHNOLOGY

An example of how to specify an early roadmap stage.

DESIGN

The Design stage of the Roadmap is aimed at driving technological advancements in new and novel design methods and tools required to enable a culture change and break the cycle of designing additive manufacturing parts like cast or machined parts.
This area includes roadmap gap closure solution ideas that avoid being constrained by fundamental limitations associated with current CAD tools and design practices that were originally developed for conventional manufacturing processes.

The technical focus and impact analysis metrics for this stage can include:

- Complexity exploitation
- Weight reduction
- Parts consolidation
- 3D functionally graded materials
- Multi-material integration
- Model-based inspection
- Product customization

PROCESS

The Process stage of the Roadmap is aimed at driving technological advancements that enable faster, more accurate, and higher detail resolution additive manufacturing machines with larger build volumes and improved part quality.
This includes targeting critical technologies and associated sub-systems where the “machine level” process performance improvements are needed.

The improvement focus and impact analysis metrics for this stage can include:

- Build speed
- Accuracy
- Repeatability
- Detail capability
- Surface quality
- Maximum part Size
- Limitations

FOCUS ON TECHNOLOGY

An example of how to specify an early roadmap stage.

MATERIAL

The Material stage of the Roadmap is aimed at building the body of knowledge for benchmark additive manufacturing property characterization data and eliminating variability in “as-built” material properties.
This includes creating a paradigm shift away from controlling process parameters and “as-built” microstructures to controlling the underlying physics of the additive manufacturing process to achieve consistent reproducible structures and therefore, “as-designed” properties.

The required technical focus and impact analysis for this stage can include:

- Standardized feedstock materials
- Benchmark material property data
- Process-property-structure relationships
- Process boundary definition
- Post-processing guidelines

VALUE CHAIN

The Value Chain stage of the Roadmap is aimed at driving technological advancements that enable change improvements in end-to-end value chain, cost and time to market for additive manufacturing produced products.
This includes qualification/certification methods, as well as the focus on integrating technologies, across the entire product cradle-to-cradle life cycle, including material and product recyclability. This stage also helps to set a priority focus on identifying advanced manufacturing opportunities for creating integrated guidelines to help identify workforce skill set needs.

The technical focus and impact analysis for this stage can include:

- Processing costs
- Feedstock material costs
- Quality control costs
- Labor productivity costs
- Post processing costs
- Supply Chain costs

ENGAGING MILESTONES

ENGINEERS MILESTONES

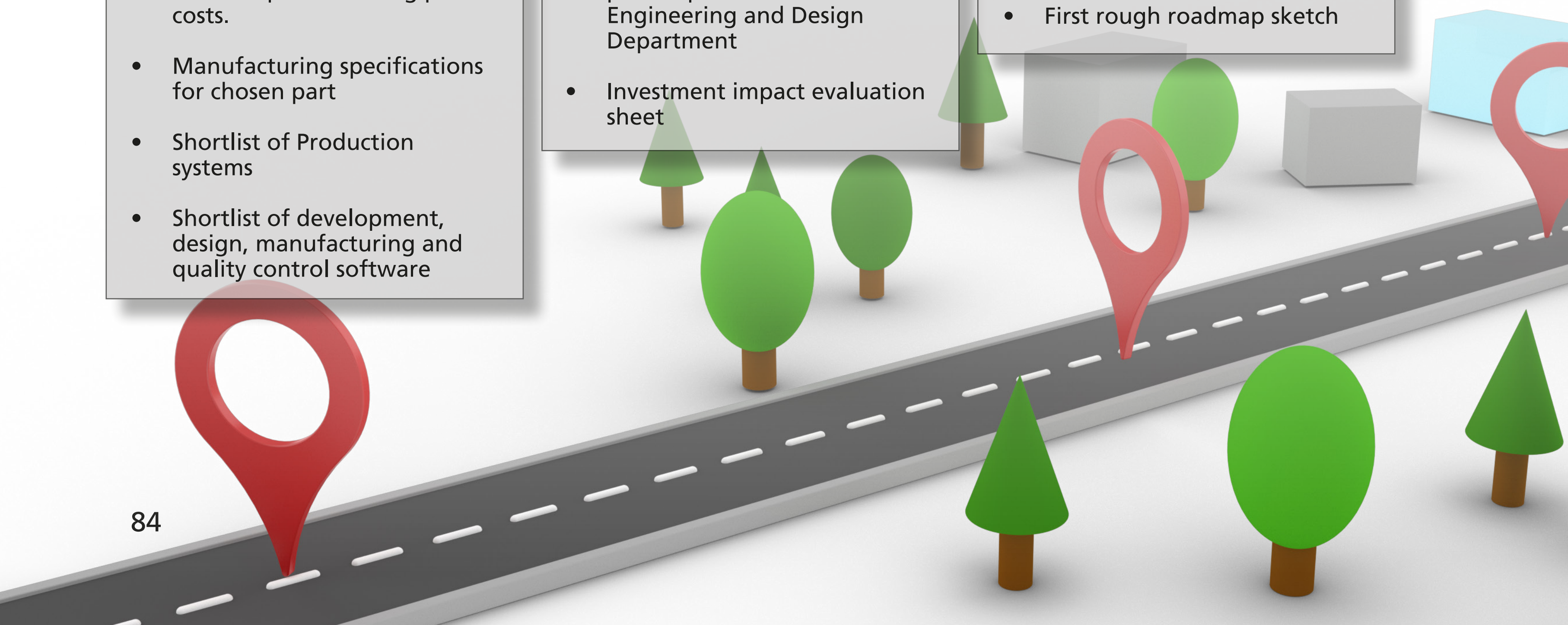
- Possibility, feasibility and use of additive manufacturing processes and systems applied to existing product and parts portfolio
- Evaluation list of parts for AM-redesign potential
- CAD design or redesign of first AM-part including primal costs.
- Manufacturing specifications for chosen part
- Shortlist of Production systems
- Shortlist of development, design, manufacturing and quality control software

OPERATIONS MILESTONES

- Collection of researched and sorted Business cases
- Definition of required skill-set for employees
- Talent acquisition plan and sources
- Feasibility studies of chosen part or product from Engineering and Design Department
- Investment impact evaluation sheet

EXECUTIVES MILESTONES

- Comparable business case for selected applications
- List of key elements for knowledge management strategy
- Change or adjustment of new business model awareness
- First rough roadmap sketch

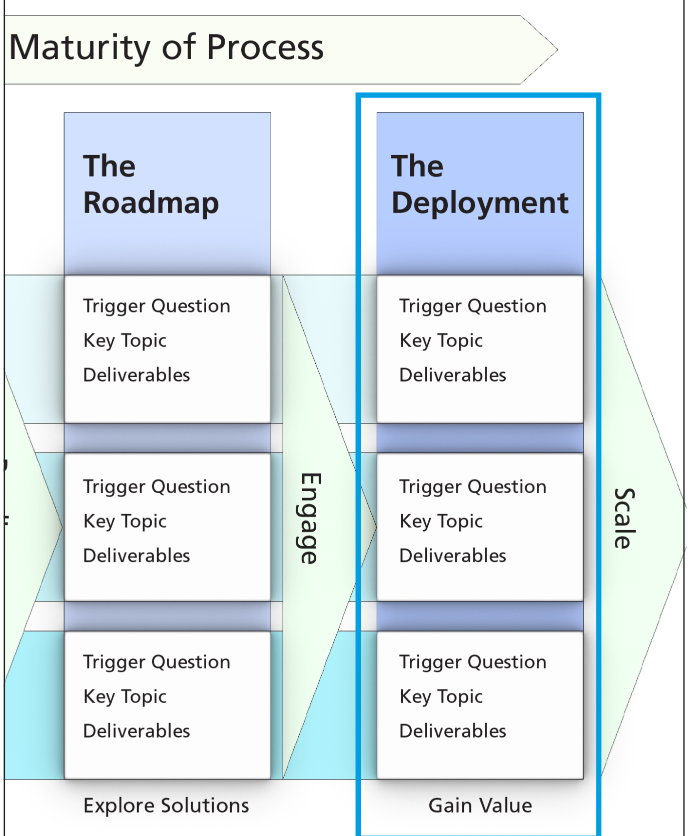


KNOWLEDGE LEVEL 3 "THE DEPLOYMENT"

Let's get serious!

COLUMN "THE DEPLOYMENT"

Goal: Additive manufacturing implementation



ENGINEER POINT OF VIEW

Trigger Questions

How can we leverage the full AM potential?

How can we improve processes?

What are the design guidelines for our products and parts?

Key Topic

Agile application development

Applied process optimization

Application Sprint

Topology Optimization

Deliverables

Successfully design, optimize, build and apply AM

Technical and design guidelines

Innovative designs like generative or bionics

AM value chain optimizations

COLUMN “THE DEPLOYMENT”

Goal: Additive manufacturing implementation

OPERATIONS POINT OF VIEW

Trigger Question

What is the right facility?

How can we transfer existing processes?

How do we scale my production?

Key Topic

Manufacturing facility planning

Repetition of machine setup

Human resources alignment

Risk assessment

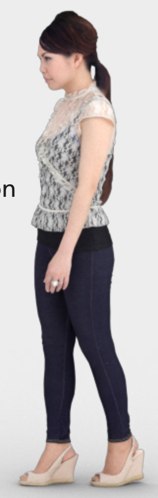
Deliverables

Production layout planning and visualization

Production flow planning and optimization

AM employee candidates

Safety regulations



EXECUTIVE POINT OF VIEW

Trigger Question

In what extent, is the existing business disrupted?

How radical is the change?

Are there new business models to into consideration?

Key Topic

New business model to employ AM at full potential

AM change management

Supplier network

Increasing market shares

Deliverables

Business assessment

The roadmap, not the draft

Investment plan

Stakeholder enablement strategy

AM BUSINESS MODELS

Unleash the full potential of AM possibilities

MASS CUSTOMIZATION

Mass customization is suitable for any large market in which customers are dissatisfied with standardized, traditionally produced products.

Among the many examples are hearing aids, orthodontic braces, orth- and prostheses, sunglasses and fashion accessories.

In the case of hearing aids from Sonova, a laser scan of a patient's ear is automatically converted into a production file, and a printer forms the shell. The main competitive challenge is to reduce the cost of acquiring individual customers' information. Hearing-aid companies first need scanning device that audiologists could easily use and scan the customers ear channels. In this hearing aid example we see that further supporting processes are required to unleash the full potential - scanning, automation and function integration.

MASS VARIETY

This model is for companies who have strong and varying preferences but don't need to adjust their products to customer specifications. Manufacturers can skip the process of collecting personal customization information and offer a wide variety of options at affordable prices. As in mass customization, units are one-offs.

Some jewelry manufacturers, take a few basic designs and make hundreds of variations, which they can show online or display as "fakes" in stores. Instead of maintaining a large and costly inventory of pieces that might not sell, retailers can wait for actual demand. With mass variety, the competitive challenge is managing the choice. Offering a broad selection will expand the market, but confronting buyers with a huge number of possibilities may overwhelm them. And even with AM, each choice adds some design costs. The products therefore are "make to order" (MTO)

AM BUSINESS MODELS

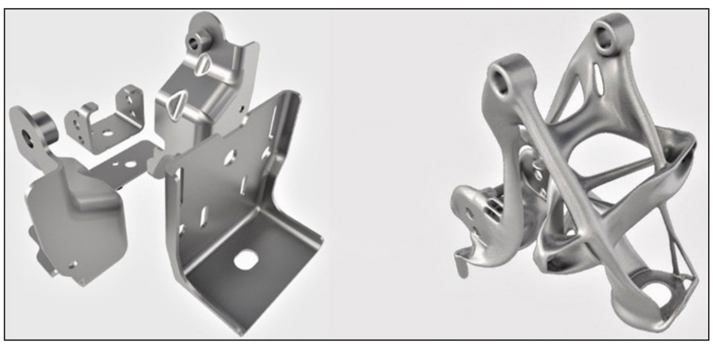
Why not be a game changer

MASS COMPLEXITY

The first two models take advantage of AM's flexibility to make a variety of product versions at low cost. This model exploits its ability to make products with highly complex designs that conventional manufacturing can't achieve and embed sensors and other elements. That ability reduces production costs while improving the product features and functions.

Boeing is using AM to build support brackets. The optimized topology of the bracket makes this load-bearing part as strong as the conventional equivalents but with much less material and as just one part, resulting in significantly reducing weight and fuel consumption.

The challenge here is simply the human imagination. Can product developers escape the conventional mindset to design products that take full advantage of AM potential?

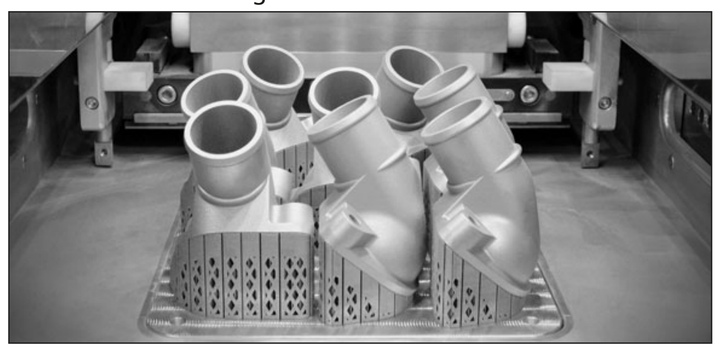


MASS SEGMENTATION

This model limits variety, offering only a few versions of a product to customers whose needs are less variable and easier to predict than with the previous business model approaches. Each version serves a single segment and differs from the others enough that traditional manufacturing would need costly new tools to make all of them. The AM technology can make them at a lower cost.

Daimler Trucks has moved toward mass segmentation. It initially used AM to make spare parts for older trucks. After it became proficient with the technology, it started producing specialized parts for some current low-volume truck models. As the number of segments served grows and the number of units sold per segment increases, the total number of parts reach a level that AM technology becomes a profitable aspect of the business.

The challenge here is deciding on the size of each segment and the number of segments to serve.



SCREENING OPTIONS

Quick approach for identifying parts, product and manufacturing potentials

ANALYSIS OF EXISTING PORTFOLIO

An understandable and simple approach for identifying AM potential in a part, assembly, product or process, is to lay-out a checklist. This list will outline key elements of must requirements, possible changes and impacts. Going through a set of questions and definitions, will help to get an idea how and where AM will make the most valuable impact in your business. Another benefit from using our 9-field matrix is the effect that each department or "user" will start their own screening process. In the end you can compare different mindsets, ideas, preferences and requirements.

DESIGN

- ☐ Complex shapes
- ☐ Lightweight design
- ☐ Adapting to existing systems
- ☐ Parametric design
- ☐ Functional integration
- ☐ Part count reduction

MANUFACTURING

- ☐ Hard to find parts
- ☐ Frequent changes to production line
- ☐ Reduce warehousing costs
- ☐ Shorten lead-time for parts
- ☐ Variability of quantity

PRODUCT LINE

- ☐ Shorten time to market
- ☐ Limited / medium size series
- ☐ Mass customization
- ☐ Tailor-made products
- ☐ On demand production
- ☐ Digital inventory

SCREENING OPTIONS

Quick approach for identifying parts, product and manufacturing potentials

PRODUCTION

- ☐ Part size
- ☐ Quantity
- ☐ Accuracy

AESTHETICS

- ☐ Color
- ☐ Coating
- ☐ Surface finish

ENVIRONMENTAL CONSTRAINTS

- ☐ Biocompatible / Skin contact
- ☐ Chemical Resistance
- ☐ UV Resistance
- ☐ Temperature
- ☐ Water tightness
- ☐ Electrostatic Discharge (ESD)

MECHANICAL CONSTRAINTS

- ☐ Vibration
- ☐ Pressure / Flexibility
- ☐ Shock Absorption

TECHNOLOGY SELECTION

☐ Selective Laser Sintering (SLS)

Quantity **Resolution** **Durability** **Cost**

1 -100k

☐ Fused Deposition Modeling (FDM / FFF)

Quantity **Resolution** **Durability** **Cost**

1 -1k

☐ Stereolithography (SLA)

Quantity **Resolution** **Durability** **Cost**

1 -5k

☐ Selective Laser Melting (SLM)

Quantity **Resolution** **Durability** **Cost**

1 -200

☐ Multi Jet Fusion (MJF)

Quantity **Resolution** **Durability** **Cost**

1 -200k

SCREENING OPTIONS

Consider the overall impact of additive manufacturing for each potential project by evaluating criteria

CRITERIA	BUSINESS IMPACT: Less Relevant for AM	Evaluate for AM	Game Changer
QUANTITY Volume of parts for the total production run	100’000+	10’000	1+
PRODUCTION INTERVAL Is there a variability about the production quantity?	All at once	Regular Intervals	On-demand
PRODUCTION DELAY When will the parts be needed?	6-8 Month	2-3 Month	Days - Weeks
COST Cost per part with AM vs traditional manufacturing	+50%	No impact	-50%
PROJECT TIME-LINE Total time-line of the project including design, validation, and production	12+ Month	6 - 12 Month	2 - 5 Month

SCREENING OPTIONS

Consider the overall impact of additive manufacturing for each potential project by evaluating criteria

CRITERIA	BUSINESS IMPACT: Less Relevant for AM	Evaluate for AM	Game Changer
GEOMETRY COMPLEXITY Is the geometry of the part especially complex?	Possible with traditional manufact.	Traditional manufact. with slight modifications	Only possible with AM
WEIGHT REDUCTION Will the new part be lighter than the original?	+50%	No impact	-50%
PARTS REDUCTION Will the redesign reduce the number of parts?	No		Yes
ASSEMBLY TIME Will the redesigned part be faster to assemble?	+50%	No impact	-50%
NON-ECONOMIC VALUE Are there other gains that can be made with AM	Not significant	No impact	Significant

SUPPLY CHAIN OR PRODUCT IMPACT

Which makes more impact on your business?

ECONOMIES OF SCALE

Economies of scale are when a company lowers the per-unit cost of production while increasing production volume. As production volumes rise, the total costs are spread out over the increased number of units produced.

MINIMUM EFFICIENT SCALE

The minimum efficient scale (MES) is when the unit cost is at its lowest possible point while the company is producing its goods effectively. MES allows a company to compete more effectively since it can produce its goods efficiently at the minimum cost per unit.

ECONOMIES OF SCOPE

An economy of scope means that the production of one good reduces the cost of producing another related good. Economies of scope occur when producing a wider variety of goods or services in tandem is more cost effective for a firm than producing less of a variety, or producing each good independently.

While economies of scope are characterized by efficiencies formed by variety, economies of scale are instead characterized by volume. The latter refers to a reduction in marginal cost by producing additional units. Economies of scale, for instance, helped drive corporate growth in the 20th century through assembly line production.

Considerations of minimum efficient scale (MES) can shape supply chains. AM has the potential to reduce the capital required to reach minimum efficient scale for production.

Changing the economies of scale has the potential to impact how supply chains are configured, and changing the economies of scope has the potential to impact product designs.

With these impacts, companies have options on how to adapt AM in to their business.

MILD ADAPTION

Companies do not seek radical alterations in either supply chains or products, but they may explore AM technologies to improve values for current products within existing supply chains.

SUPPLY CHAIN MODIFICATION

Companies take advantage of scale economies by the use of AM as a potential enabler of supply chain transformation for the products they offer.

PRODUCT MODIFICATION

Companies take advantage of the scope economies by the use of AM technologies to achieve new grounds of performance or innovation in the products they offer.

BUSINESS MODEL MODIFICATION

Companies modify both, supply chains and products for new business models.

SUPPLY CHAIN OR PRODUCT IMPACT

Innovation in product and supply chain

High Supply Chain change

PRODUCT MODIFICATION

Objective:
Balance of growth, innovation and performance

Value:
Balance of profit, risk and time

AM Capabilities:
Mass customization | Product functionality
Market responsiveness | Increased part complexity

BUSINESS MODEL MODIFICATION

Objective:
Growth and innovation

Value:
Profit with revenue and risk focus

AM Capabilities:
Mass Customization | Manufacturing at the point of use
Supply chain disintermediation | Customer empowerment

MILD ADAPTION

Objective:
Performance

Value:
Profit with a cost focus

AM Capabilities:
Rapid Prototyping | Custom tooling
Low batch production | Jigs and fixtures

SUPPLY CHAIN MODIFICATION

Objective:
Performance

Value:
Profit with a cost and time focus

AM Capabilities:
Manufacturing closer to point of use | Responsiveness and flexibility | Reduction of required inventory | Demand uncertainty management

High Product Change

SMART FACTORY

Why not team up AM with other new technology?

WHAT IS A SMART FACTORY?

The term "smart factory" can be translated literally as "intelligent factory". Production processes have always had to be intelligently organized in order to be as efficient and profitable as possible.

Historically, this already began in the splitting of production processes in factories, continued in industrialization with new machines, and reached automated production processes presently. But the labor cost is still the main and essential cost factor of such factories and is predestined for human errors.

The complete networking of automation has changed this situation: All equipment, processes, and products are interconnected through the IIoT (Industrial Internet of Things). With the help of the permanent exchange of data between production facilities and products, as well as between production facilities and logistics systems, the smart factory fundamentally organizes itself. Humans only have to initiate, monitor and evaluate these processes in order to correct errors or make optimizations. But the smart factory does not end with the creation of a product. The smart factory also enables networking and communication with other areas of the company as well as with suppliers and customers. This begins with order acceptance and extends to warehouse logistics and delivery.

WHAT CONSTITUTES A SMART FACTORY?

A smart factory consists of the intelligent networking of all its production components. Cyber Physical Systems (CPS) form the basis for this. In these systems, IT components and software are connected with mechanical and electronic systems. This not only allows data to be exchanged between them, but also enables the infrastructure of the entire production process to be managed and controlled.

In contrast to manual acquisition and input of commands, there are no delays during the production process: analysis, command transmission and control of stationary and mobile systems take place in real time via the IIoT.
Products or components are controlled in the manufacturing process via RFID (Radio Frequency Identification) or Bluetooth. Due to the adaptability and individualized production processes for all areas and industries, CPS represent a core component of the Smart Factory within Industry 4.0.

WHAT ROLE DO PEOPLE PLAY IN SMART FACTORIES?

The implementation and use of smart factories also changes the role of humans. When production processes are largely automated, the routine tasks that were not previously performed by machines are reduced. Nevertheless, humans still play an important role in the Industry 4.0:
Digitized and self-controlling processes still require control, while at the same time employees in production carry out error diagnoses and optimizations.

In addition, developers are responsible for the fundamental design of the smart factory. Both the production processes to be automated and the networking with other company divisions and external systems also require development, monitoring and adjustments.

In the future, however, these activities will take place less and less "on site" and will instead shift to virtual space. Access to all production components and external interfaces via augmented reality significantly reduces physical contact. On-site maintenance will only be necessary in the event of mechanical or hardware problems.

ADVANTAGES OF A SMART FACTORY

The smart factory offers considerable advantages over the usual infrastructure of a company. These result in an optimized value creation process and improved competitiveness in the face of increased individual customer requirements. A Smart Factory offers the following advantages for companies:

Automated processes:
The insights gained from Big Data result in networked and fully automated processes. This eliminates latencies and unused working time.

Higher productivity:
The optimized processes result in higher product output within the same timespan.

Lower production costs:
Needs-based resource procurement and shorter production times result in lower costs.

Flexibility and individual production (Batch size 1):
Optimized demand planning within the automated processes enables the production of very small quantities at the same unit prices as in mass production.

Automated ordering and delivery processes:
With networked order entry, further processing, production and delivery logistics, an order runs completely automatically and thus faster.

More information:
With constant data collection and evaluation (Big Data), companies have more knowledge about their products and their production process in a short time.

CHALLENGES FOR SMART FACTORIES

The development and implementations of smart factories in the context of Industry 4.0 means a fundamental transformation process of previous forms of production. Many of the subareas previously located locally within the company are being outsourced to the virtual environment (cyber-physical systems, ERP, Digital Twin) or even to external service providers (cloud services). At the same time, considerable amount of data is generated during the production process, which must be protected accordingly.

In order to benefit from the many advantages of a smart factory, following topics must be considered.

Security:
A very important aspect in the establishment of a smart factory is the security of the networked company infrastructure as well as the data collected in the context of Big Data. It must be ensured that all data is processed in compliance with the respective data protection regulations of the location and at the

SMART FACTORY

Why not team up AM with other new technology?

same time are protected from access by cyber criminals. To this end, the employment of internal cyber security experts and the outsourcing of data to specialized cloud providers is essential.

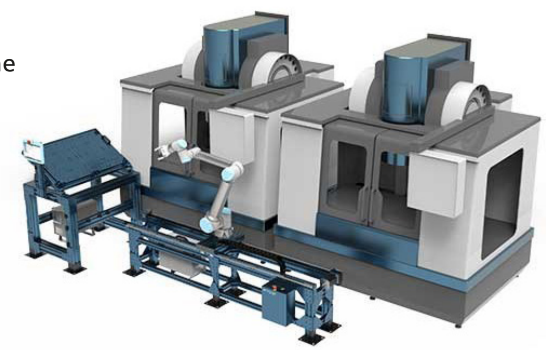
Infrastructure:
A production chain cannot be automated overnight. Sub-processes should first be digitized step by step and in coordination with each other, for example through cyber-physical systems and embedded systems. At the same time, a network infrastructure must be established to establish the IIoT, which can process big data in real time through cloud services and edge computing.

Training and education:
Although production in a smart factory is fully automated, the focus is still on people: Without employees monitoring the entire infrastructure, errors cannot be corrected. At the same time, an ongoing optimization process must be ensured to allow for adjustments of flexible incoming orders and increasing individual production. The operation of cyber-physical systems or the mapping of processes by a digital twin also requires appropriately trained employees. The demands on skilled workers are therefore increasing considerably in the smart factory. Ultimately, the successful operation of a smart factory is only made possible by the appropriate training and continuous professional development of the employees.

SMART FACTORY SCALING WITH AM

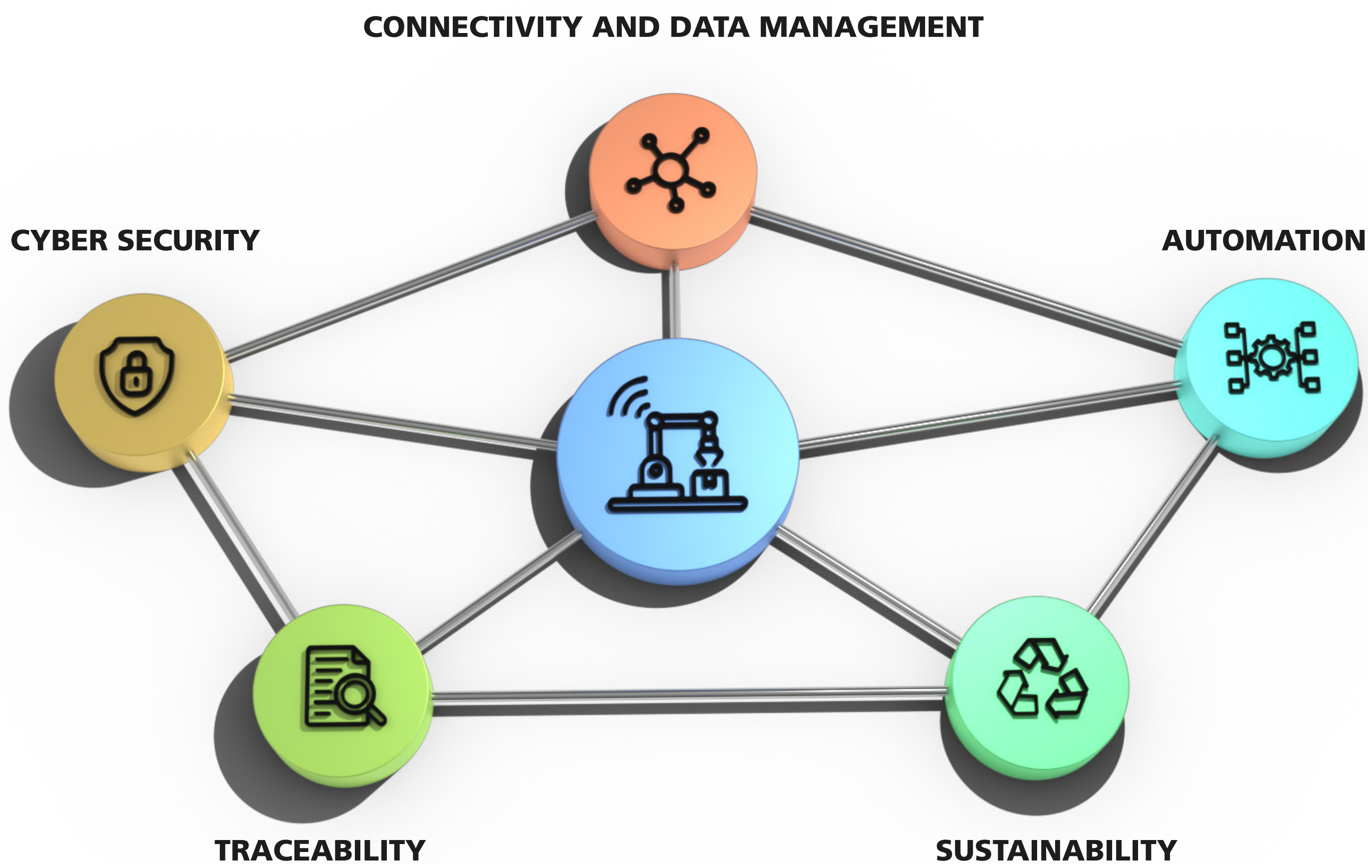
COVID-19 has shown the world that traditional supply chains and production systems need to become more adaptable and agile to keep up with the changes and challenges brought on by the current crisis.
While many companies are adopting AM, they need to use the right tools and processes to establish a traceable, automated, secure and sustainable work-flow.
Much of these requirements can be achieved with the help of MES (Manufacturing Execution System) designed for the needs of additive manufacturing. Additive MES software enables manufacturers to link production planning and control and execution into a digital thread that leverages data to achieve greater visibility and establish best practice processes across the enterprise.

Using a strategic goal, the right tools and technologies, manufacturers can lay down the foundation a long-term success of additive manufacturing in the smart factory.



SMART FACTORY

Connect the power



DEPLOYMENT MILESTONES

ENGINEERS MILESTONES

- Reliable and scalable end to end AM process layout
- Clear guideline of design for additive manufacturing, applied to the chosen products or parts
- New product concepts only produceable with AM
- Concept for new Software implementation, application and training
- Know supporting and automations systems

OPERATIONS MILESTONES

- Factory setup concept
- Factory locations and partners
- Factory long-term scale concept
- AM Supply Chain Management
- List of knowledge asset for employee recruitment
- Employee safety guidelines
- Change management process organization

EXECUTIVES MILESTONES

- Roadmap ready to communicate to relevant stakeholders
- KPI for new or adapted business model
- Cost structure overview
- Investment plan
- Stakeholder enablement strategy
- Alignment of organizational structure

NOW IT IS YOUR TURN !

Lift off for a successful change to AM

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How can additive manufacturing and the relevant processes be integrated into existing and new business models and how can they be built up sustainably? The present playbook provides an orientation framework for a correct interpretation and approach in Additive Manufacturing and helps companies to successfully implement AM, including upstream and downstream processes. The outline and its content is structured and presented in such a way that relevant decision support is mapped to all concerned business levels, from the CEO to the executive. Various use case illustrations are supplemented with figures and cost calculations.

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