Design rules for 3D-printing

Agenda

- 3D-printing
- Printer specific determination of design-guidelines or -principles
- General design-guidelines or -principles
- General design-guidelines or -principles for different printing principles
  - Selective Laser Melting (SLM)
  - Electron Beam Melting (EBM)
  - Stereolithography (SLA) (STL)
  - Fused Deposition Modeling (FDM)
  - Laser sintering (SLS)
  - Multi Jet Fusion (MJF)
  - Polyjet

History of 3D printing

1980

1982 Description of first print process to produce a solid object

1984 Invention of 3D printing by the US-American Charles W. Hull

1986 First patent application by Charles W. Hull

1988 First commercial 3D printer available on free market

1989 Carl Deckard patents the Laser Sintering (SLS)

1990

1992 Scott Crump patents the FDM-Procedure

2000

Beginning 2000 Production of first tools, mold and small batch of complex end products

2009
3D printing better known in the media.
First provider for printing orders

2010

2012 Release of the Replicator 2 through the company Marker Bot → Also available for consumers

2014 IPO of some 3D printing companies (e.g. SLM)
First 3D printer for metal

2016 Boeing patents 3D printing procedures for floating objects

3D printing – areas of application

Architecture	Traffic planning	Teaching aids	Textile industry
Design & Concept	Art	Jewelry	Archeology
Marketing	Research	Medical Technology	Landscape design
Engineering and steel design	Individual gift ideas	Sand casting master forms	Urban planning
Automobile industry	Finite elements	3D ultra-sound	

→ Nearly everyone gets in contact with the topic 3D printing.

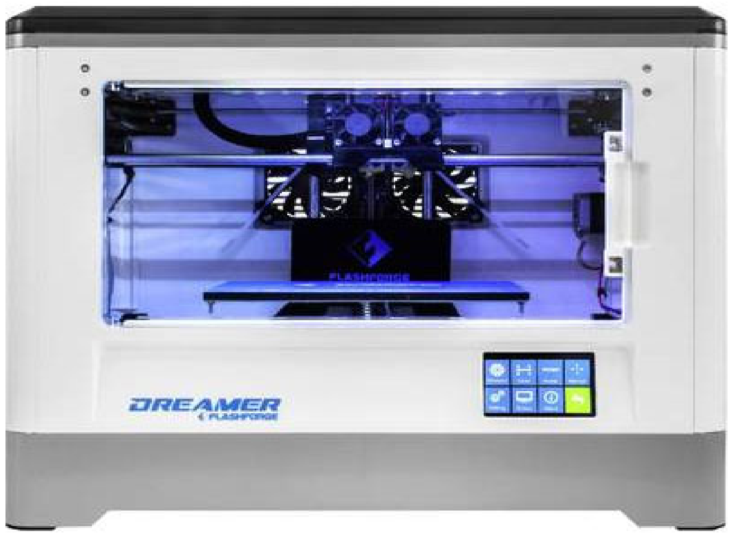
→ Many of them have to think about designing.

→ Design guidelines / directives could be an aid.

Source: www.3d-solutions.at

Printer specific-design-rules

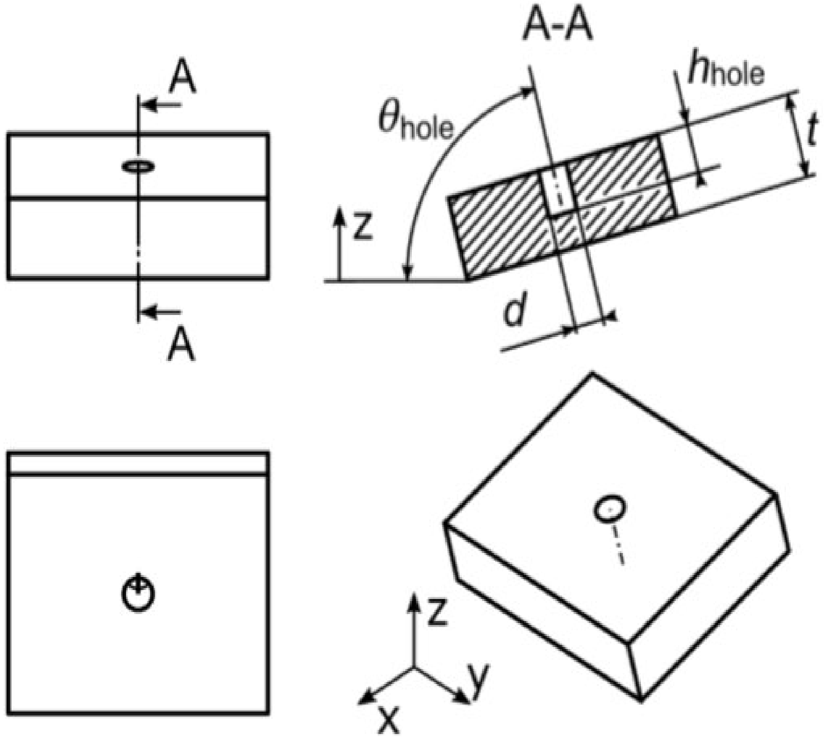
Printer:	Flashforge Dreamer Dual 3D-printer
Procedure:	Fused Deposition Modeling (FDM)
Materials:	PLA, PVA, ABS, HIPS and Soft-Filament
Layer thickness:	0,1 until 0,4mm => 0,2mm selected
Installation space:	230x150x140mm
Specials:	Dual Extruder
Costs:	777,99 € incl. VAT
Test procedure:	Based on VDI 3405

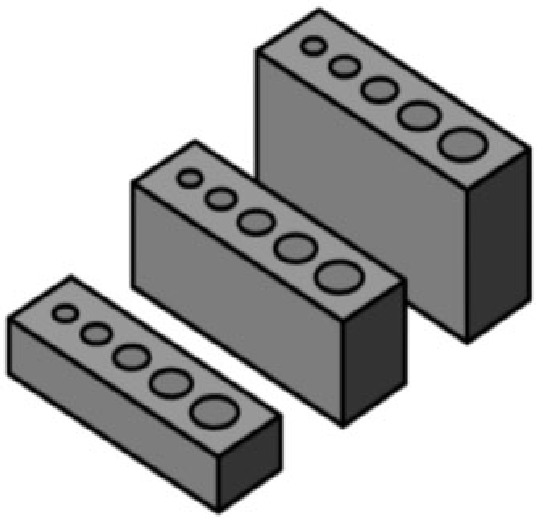


Picture source: Conrad Onlineshop

Printer specific-design-rules

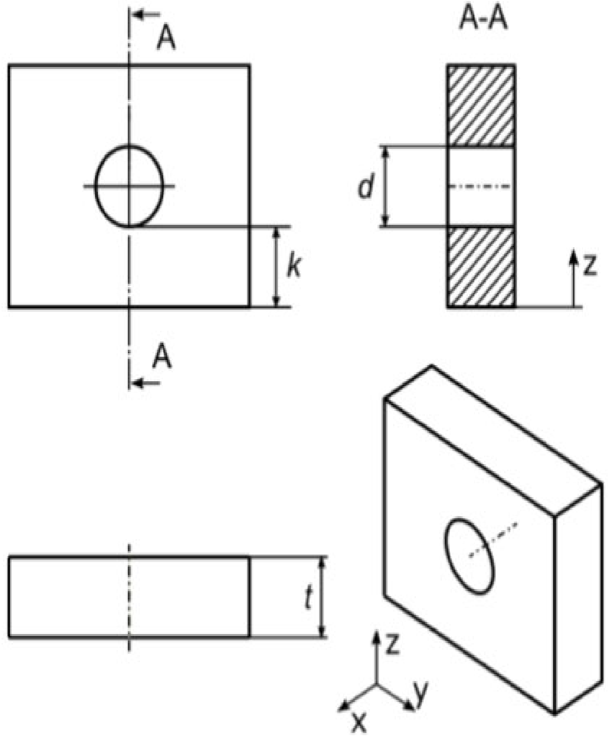
Minimum hole diameter:

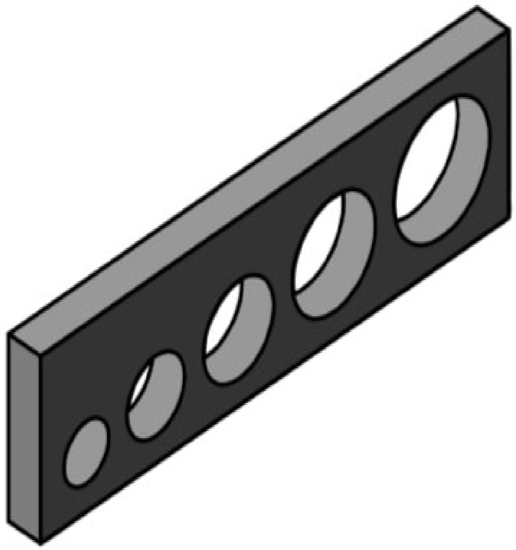




Printer specific-design-rules

Maximum horizontal hole diameter:

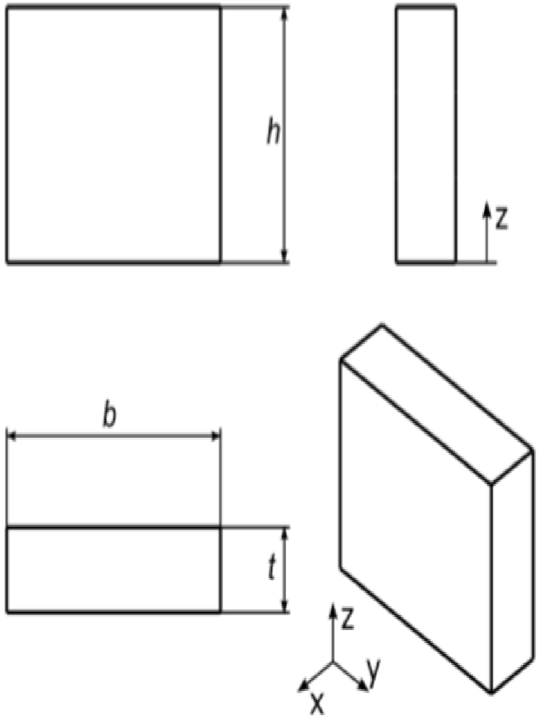


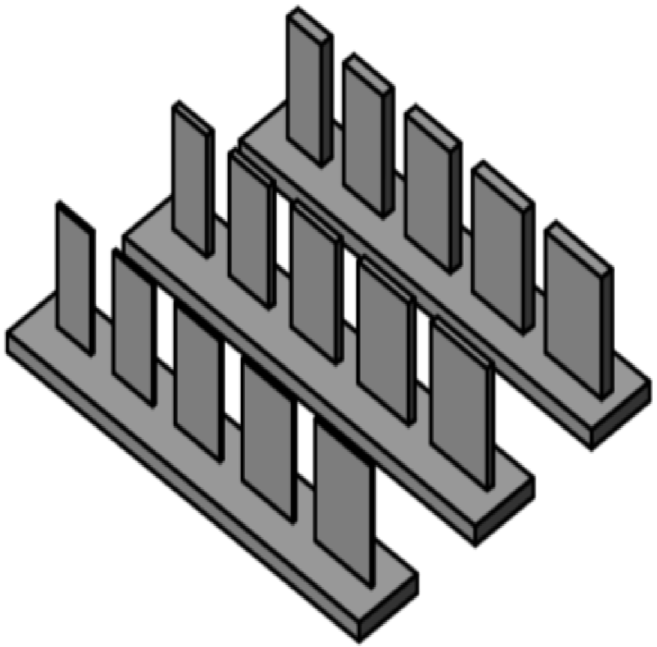


Picture source: VDI 3405 Sheet 3.2

Printer specific-design-rules

Minimum wall thickness of free standing walls:

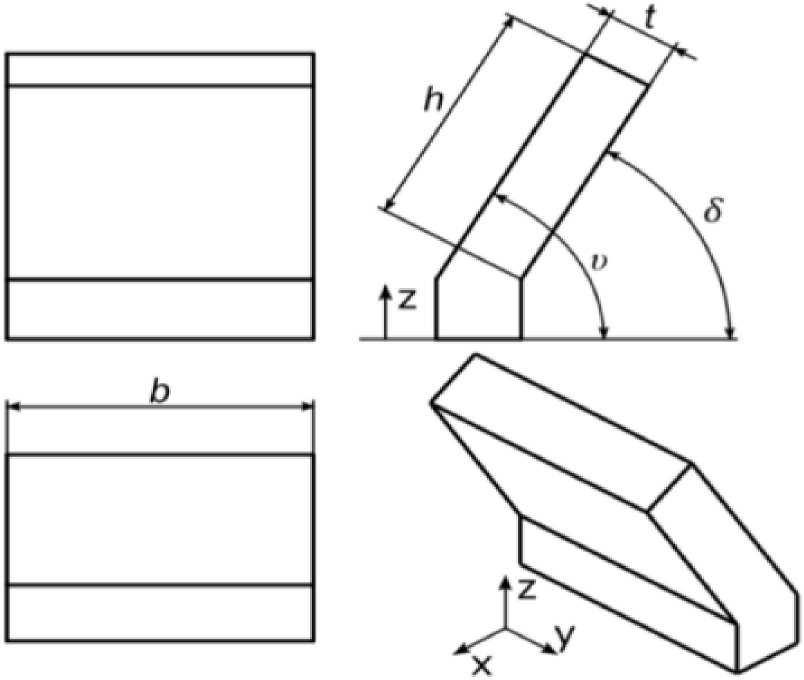


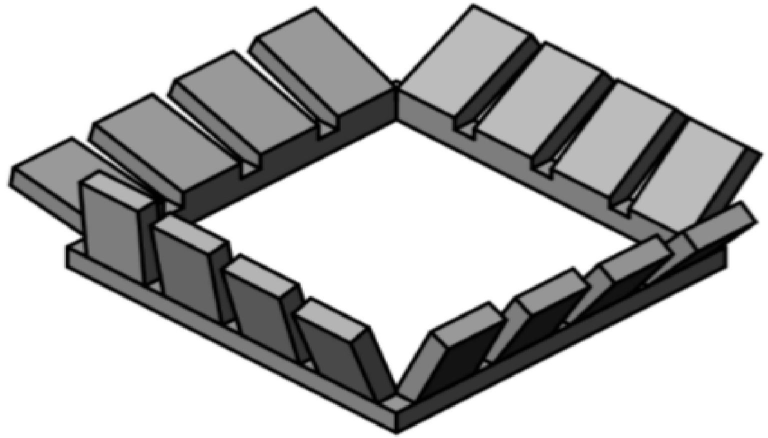


Picture source: VDI 3405 Sheet 3.2

Printer specific-design-rules

Minimum angle of inclination of free-standing walls:

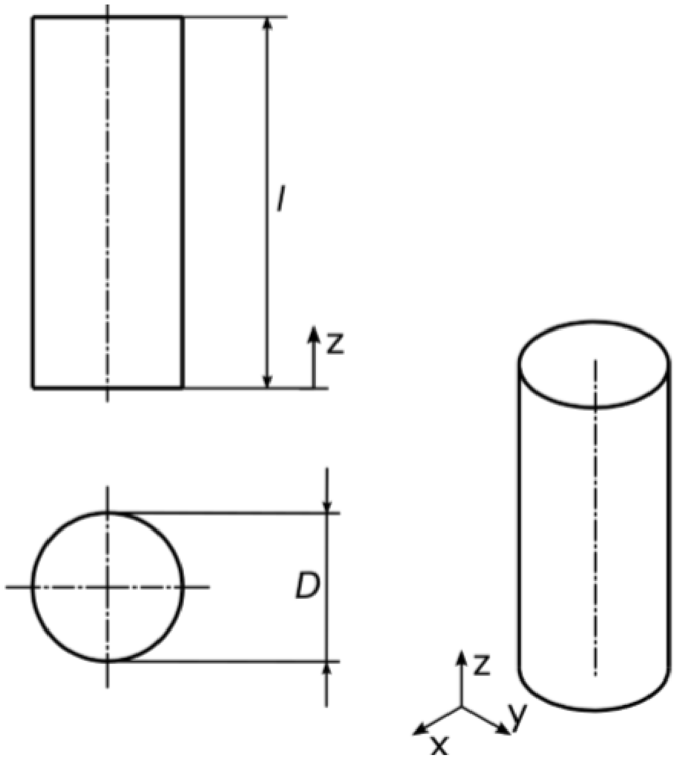


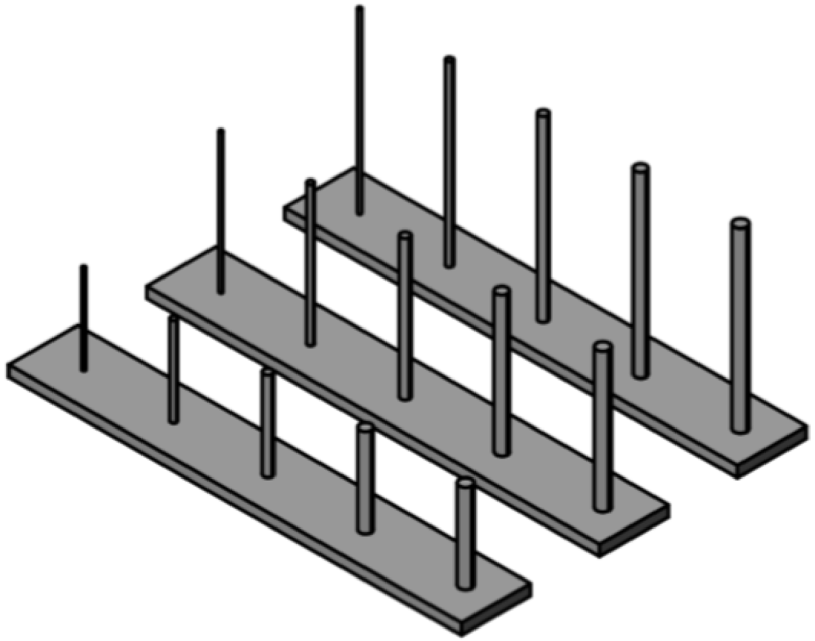


Picture source: VDI 3405 Sheet 3.2

Printer specific-design-rules

Minimum free-standing dowel pin:

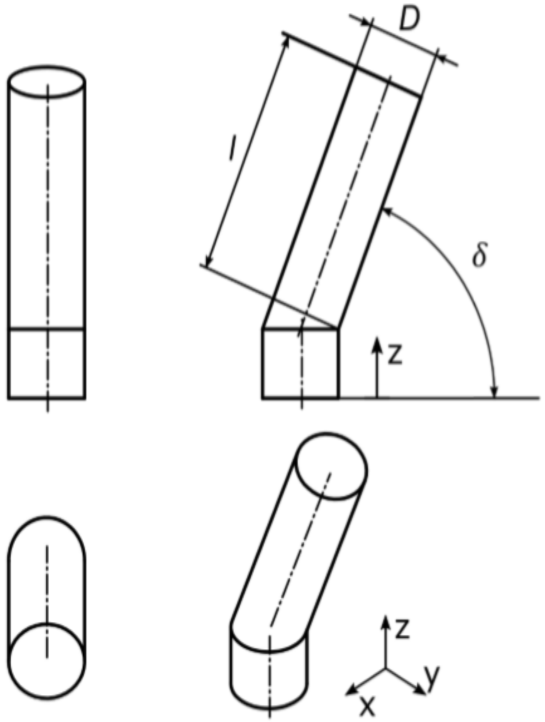


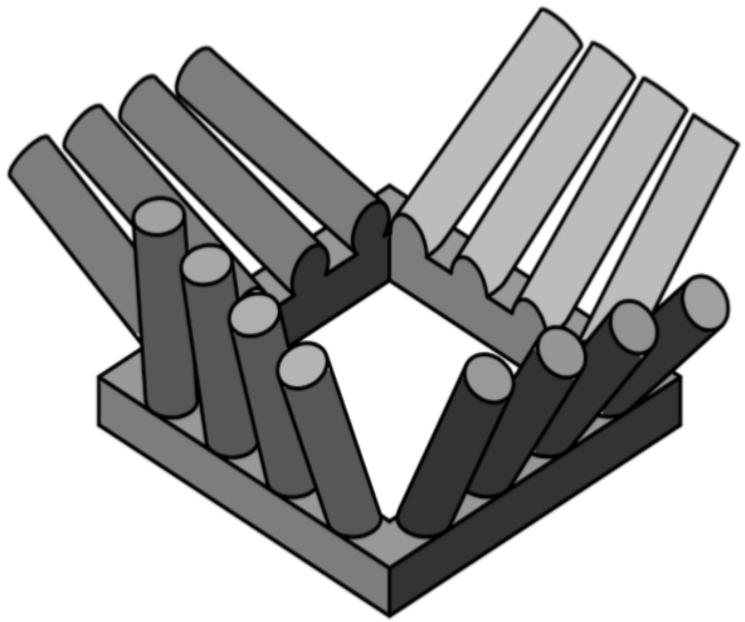


Picture source: VDI 3405 Sheet 3.2

Printer specific-design-rules

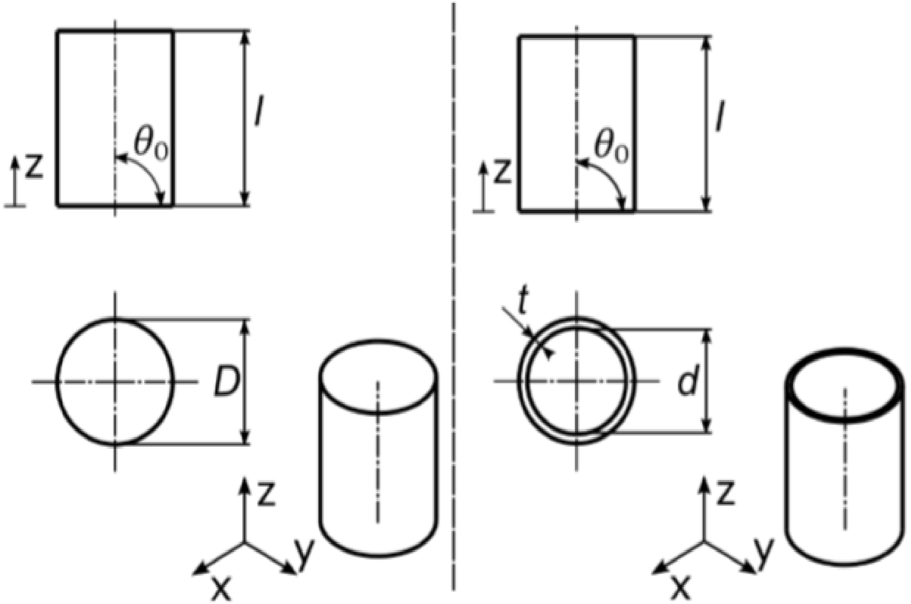
Minimum angle of inclination free-standing dowel pins:

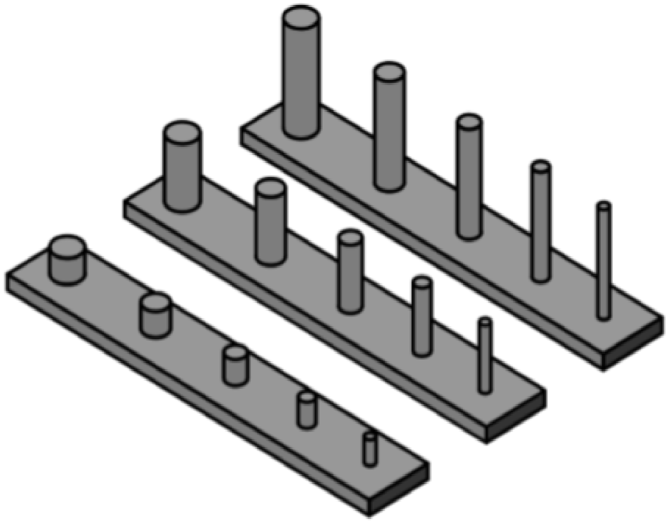




Printer specific-design-rules

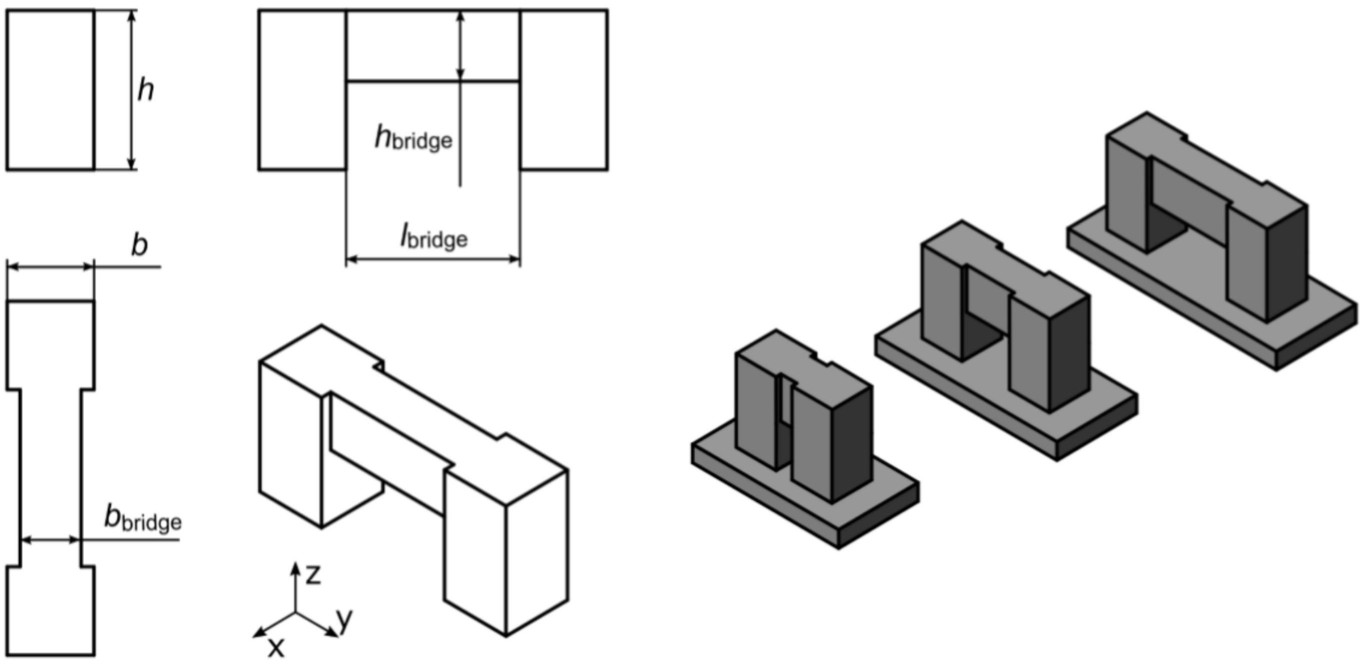
Roundness with different inside- and outside parameters:





Printer specific-design-rules

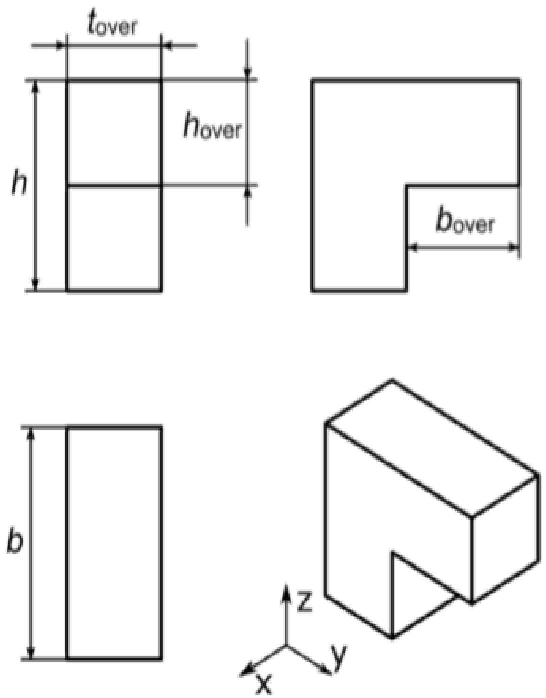
Maximum self-supporting bridging:

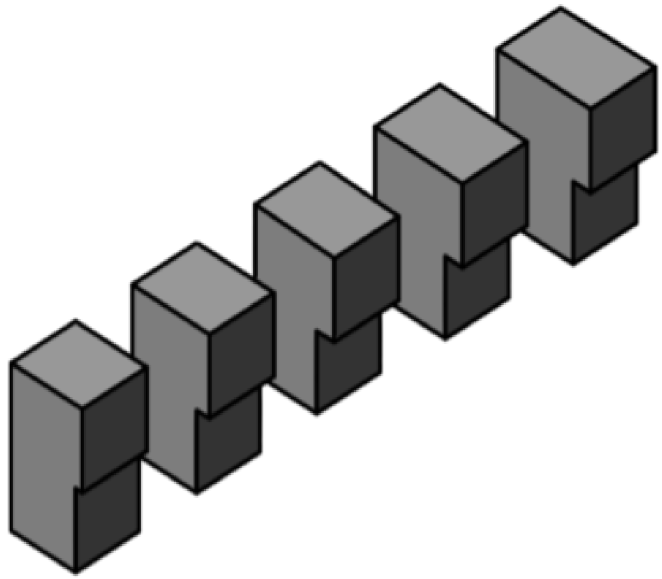


Picture source: VDI 3405 Sheet 3.2

Printer specific-design-rules

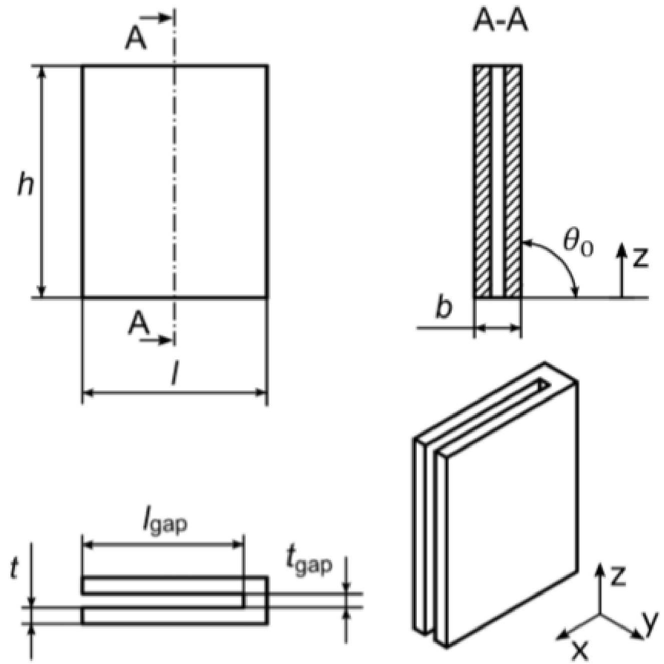
Maximum self-supporting overhang:

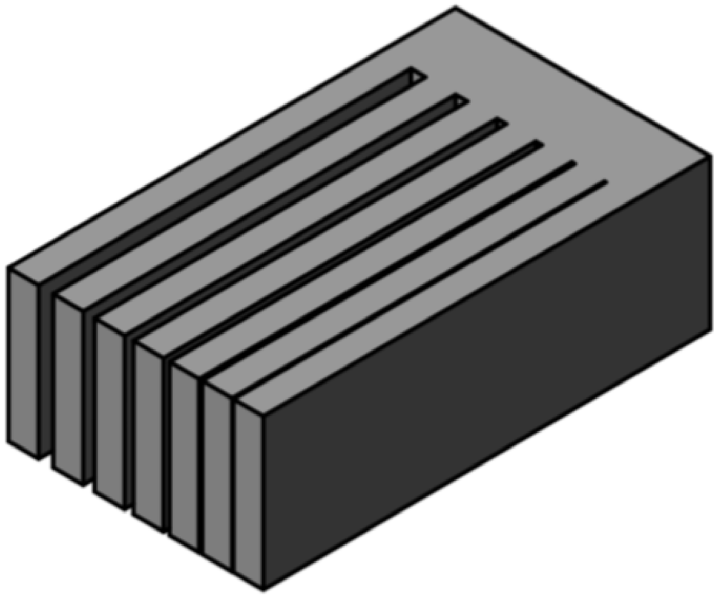




Printer specific-design-rules

Minimum gap dimensions:

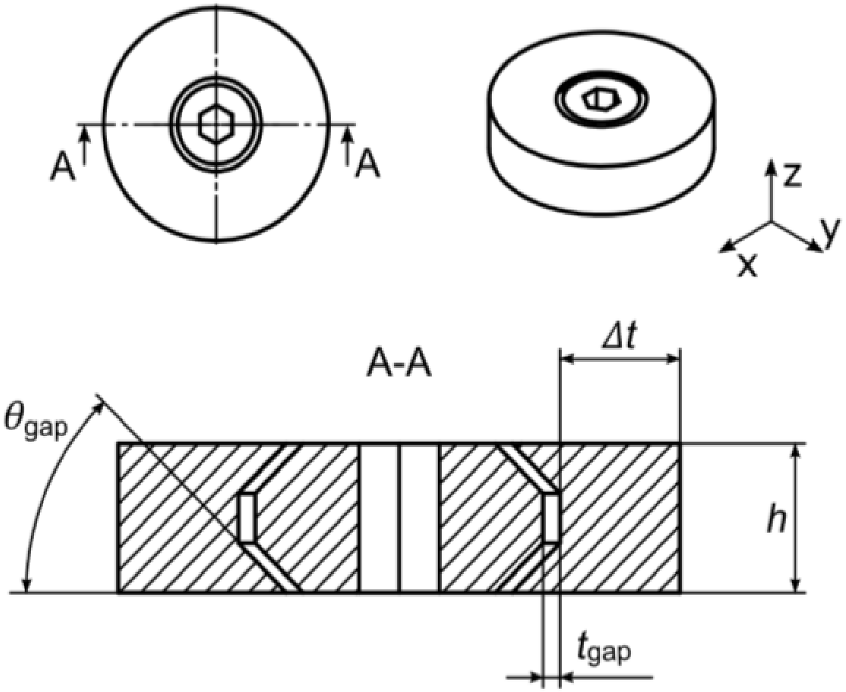


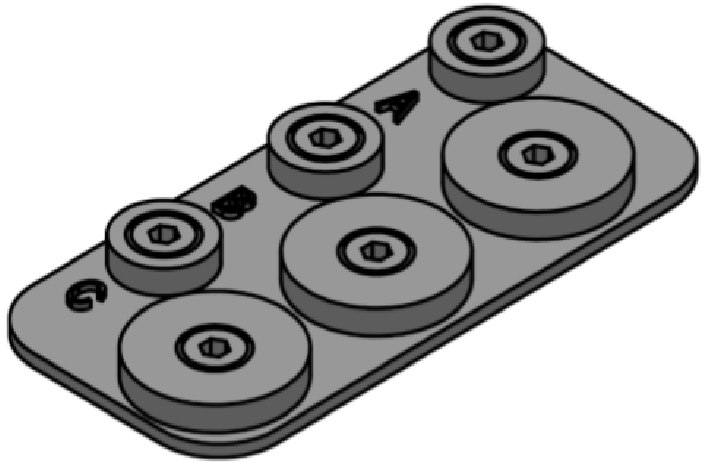


Picture source: VDI 3405 Sheet 3.2

Printer specific-design-rules

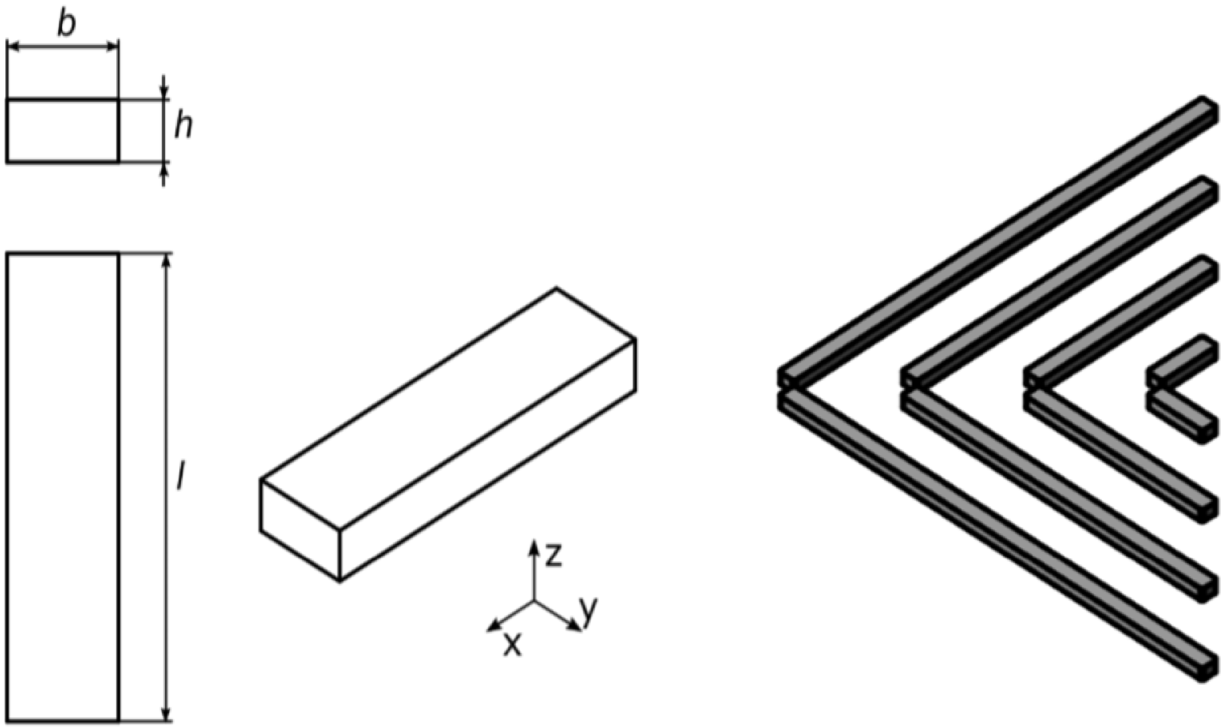
Gap dimensions for movable parts:





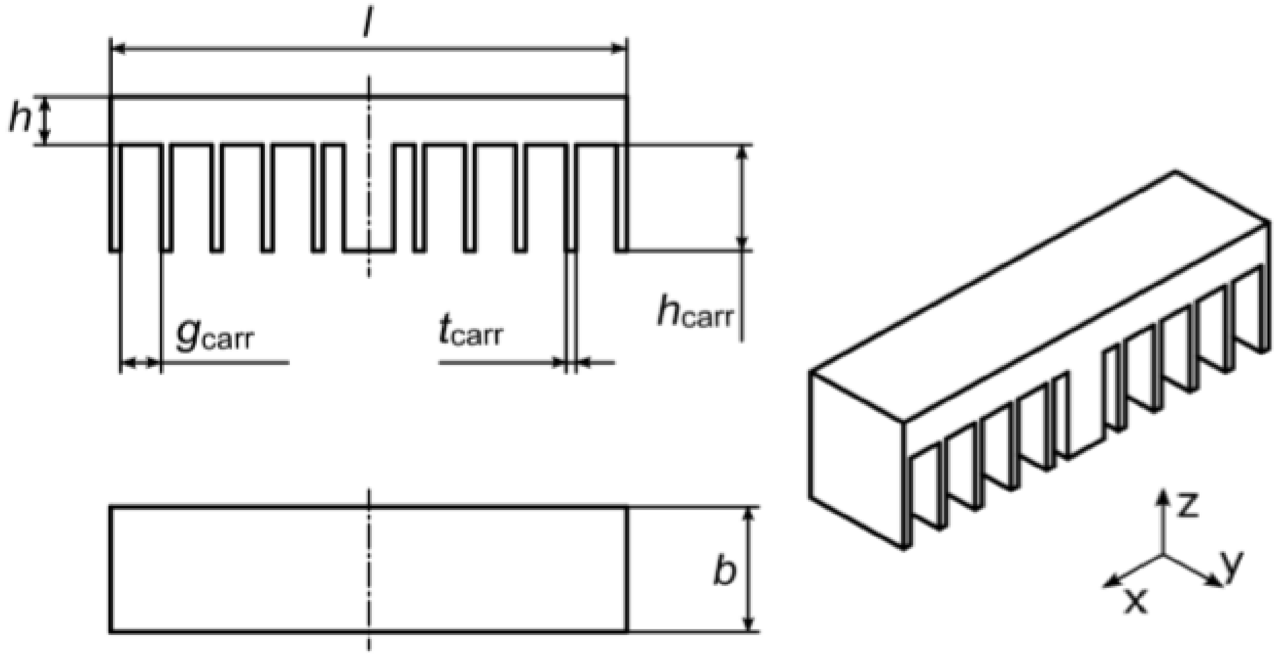
Printer specific-design-rules

Size accuracy:



Printer specific-design-rules

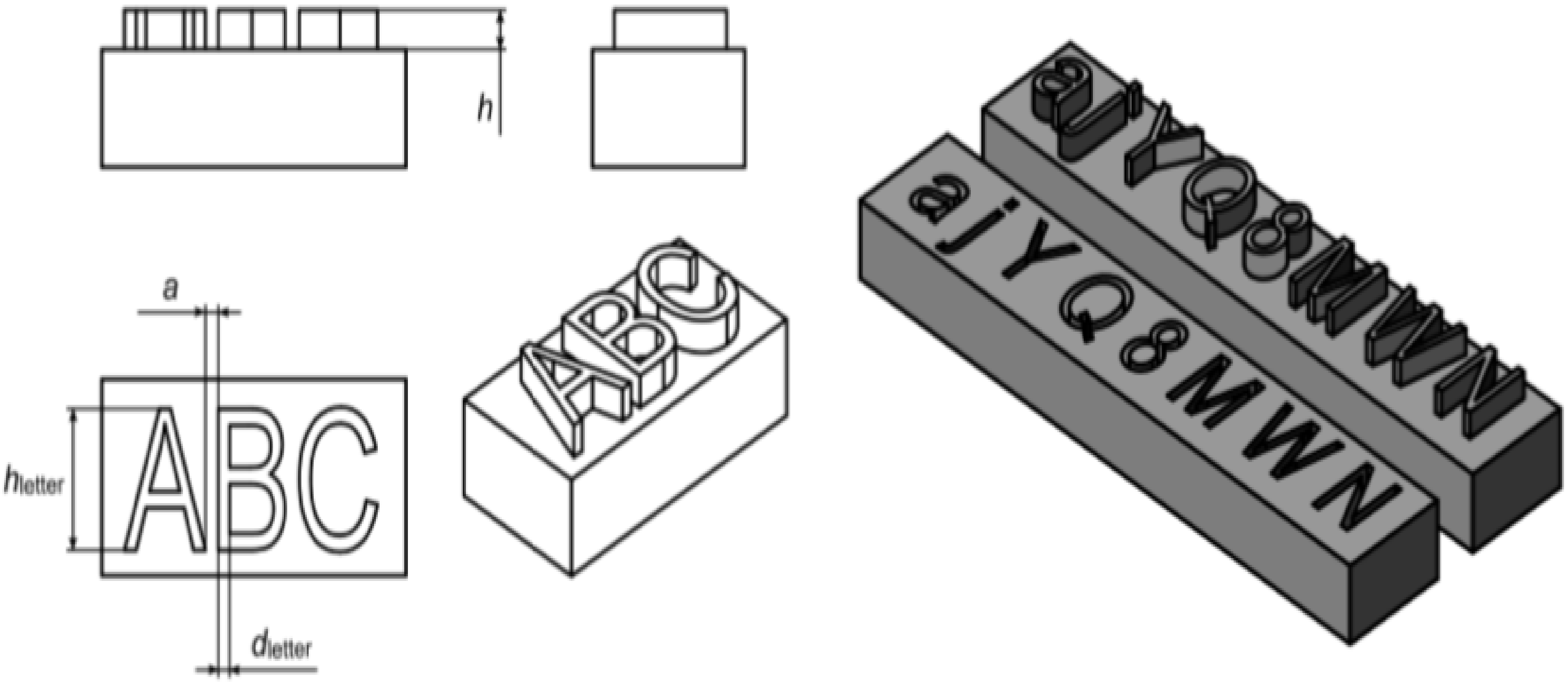
Delay with a flat oriented bar that es placed symmetrically on oriented struts:



Picture source: VDI 3405 Sheet 3.2

Printer specific-design-rules

Printable fonts:



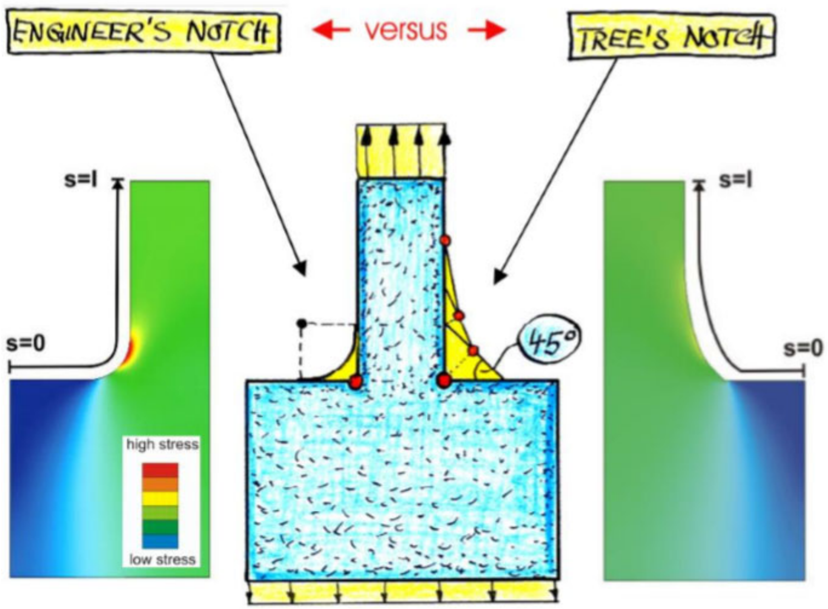
Printer specific-design-rules

Table	Flashforge Dreamer
Minimum Wall thickness	1-2mm
Minimum cylinder diameter	1-2mm
Minimum hole diameter	1-2mm
Maximum horizontal hole diameter	8mm
Critical angle of inclination	15° (wall) 45° (cylinder)
Self-supporting bridging	11mm
Self-supporting overhang	1-3mm
Minimum gap dimension	0,2mm

Meshing components	30° gap ≥ 0,6mm 45° gap ≥ 0,3mm 60° gap ≥ 0,3mm
Delay	0,7mm x 90mm on both sides
Size accuracy	0mm to -0,2mm
Fonts	Set font: Arial Standard Point ≥ 16 Embedded font: Arial Standard Pkt. ≥ 16

General design-guidelines or -principles

- Topology-optimizing
  - Material- und weight optimized constructing
    (restrain from conventional way of constructing)



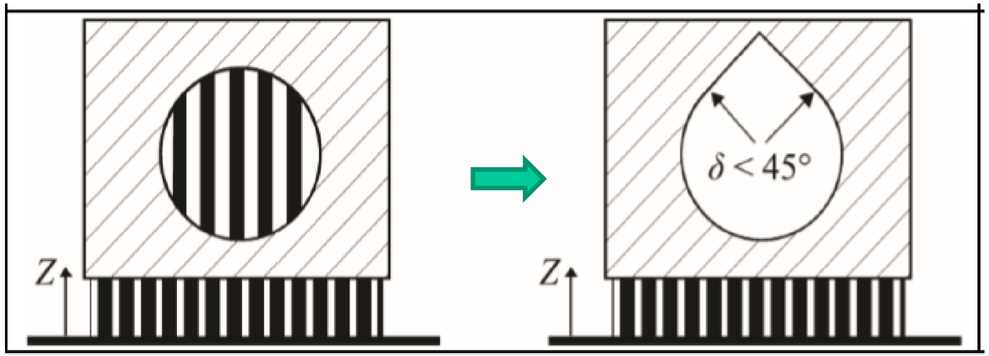
- Avoidance of stress peaks
  - Usage of radius or pull triangles

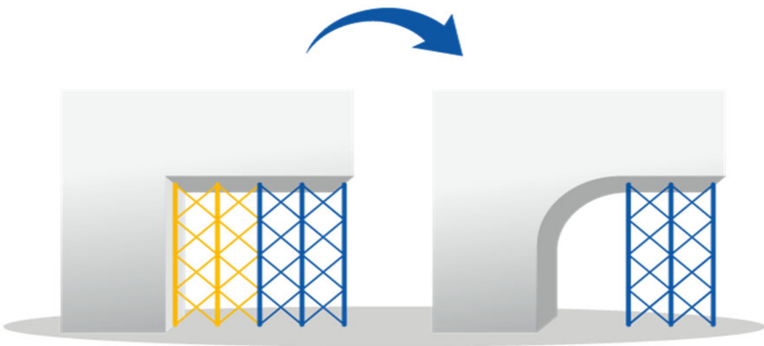
Source: 3Dnetzwerk, Die 10 wichtigsten Richtlinien für die additive Konstruktion

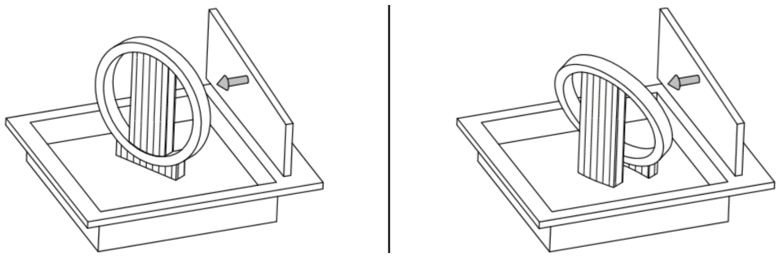
Source: 3Dnatives, Topologie-Optimierung für den 3D-Druck

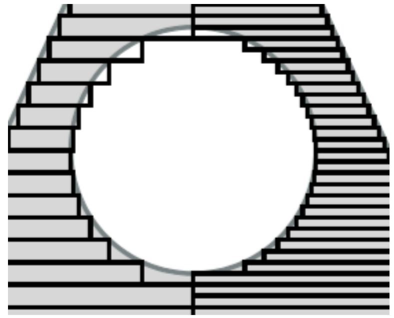
General design-guidelines or -principles

- Horizontal holes
  - Eventually necessary usage of support
  - Design errors by stair step effect





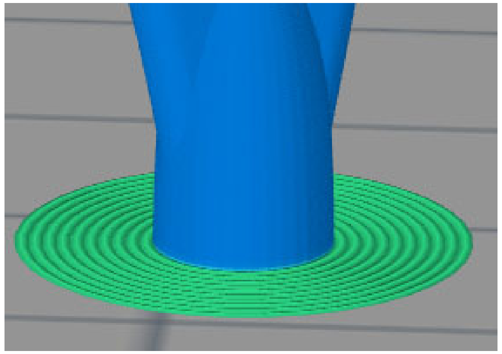




- Reduction of support
  - Use of radius
  - Optimized component alignment

General design-guidelines or -principles

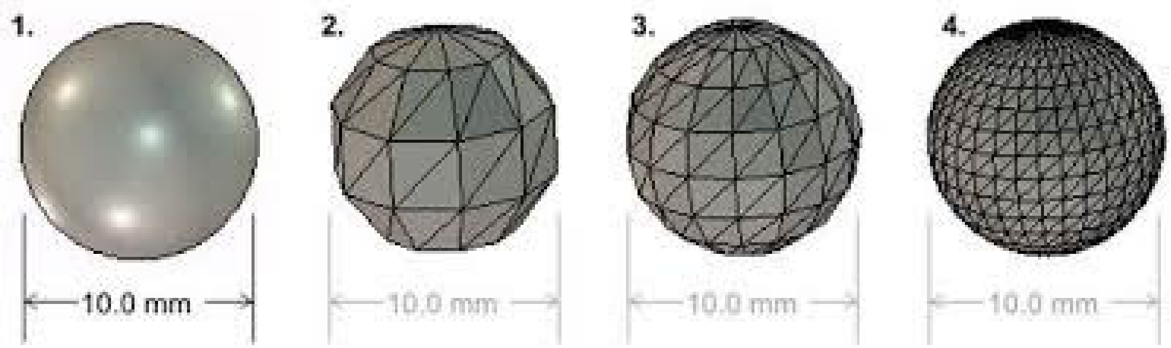
- Printing-bed-contact
  - Usage of raft-structures
  - Optimized Component alignment



Source: Simplify3D, Rafts

- Integration of normed parts
  - magnets, nuts, threaded bush, …

- Accuracy
  - select correct STL-resolution



Source: Mark3D, Die perfekte STL-Datei für Ihren 3D Druckauftrag

General design-guidelines or -principles

- Single part design
  - Linking of single functions
  - Using constructing freedom

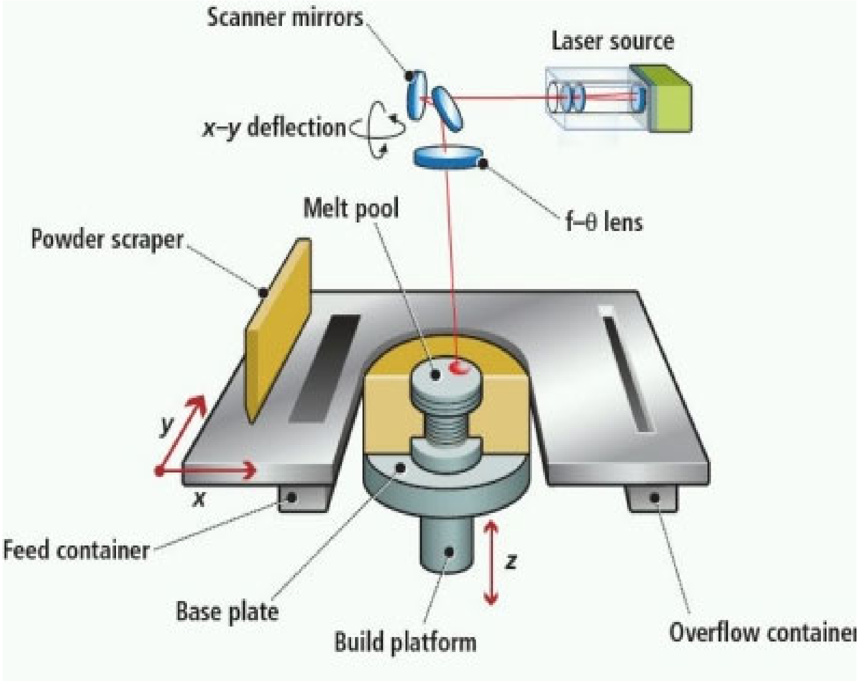
- Large components
  - Distribute in producable component segments

- Post processing
  - For exact shape elements
  - (keep allowance and mind clamping elements in mind)

Printer specific-design-rules

Selective Laser Melting (SLM)

Basic material:	metal / metallic alloys
Material form:	powder
Material distribution:	shaver
Way of merger:	with laser
Laser alignment:	with mirror



Printer specific-design-rules

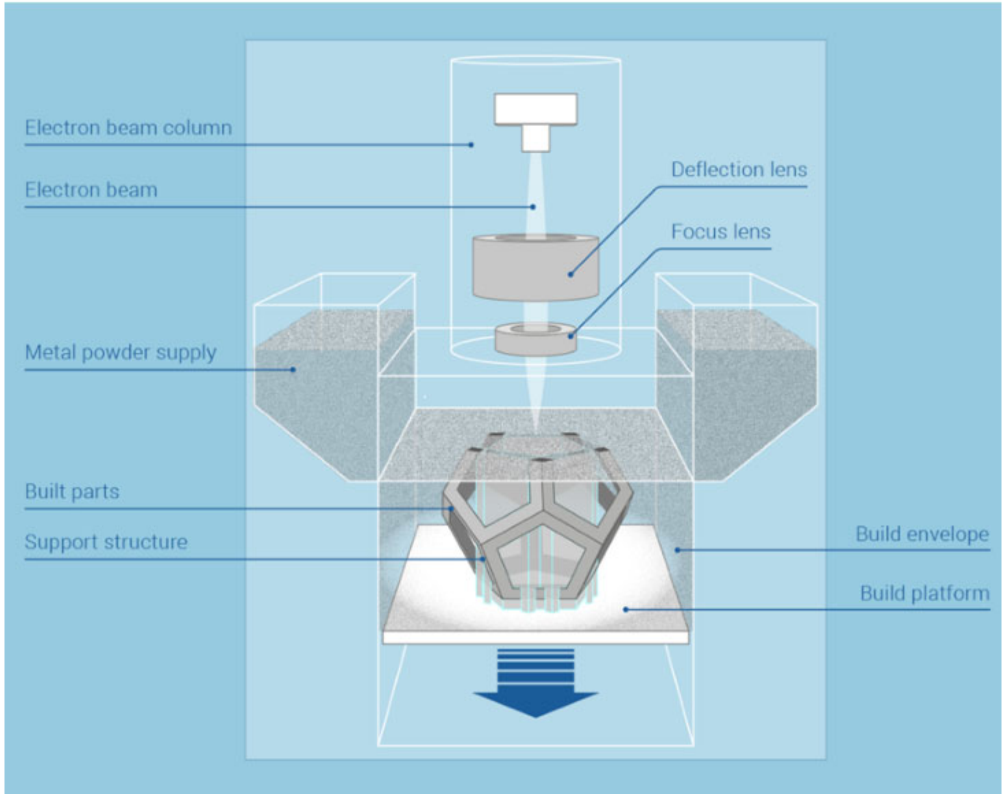
	Selective Laser Melting
Wall thickness	>= 1mm
Powder removal	Simple outline: One hole with D > 3mm Complex outline: Eventually more holes with D min 7mm
Accuracy	Min. line thickness = 0,4mm Min. line depths = 0,15mm Min. line height = 0,4mm
Surface quality	Upskin-surfaces better than Downskin-surfaces
Component alignment	- Overhangs in shaving direction - Thin components elongated in shaving direction - Thin components vertically to component level

	Selective Laser Melting
Thermic induced tension	- Select low Transverse surfaces - Avoidance of larger accumulation of materials
Anisotropy	- Line of force on component level
Accuracy	- ±0,2% (min. ±0,1mm – ±0,2mm) - Form deviation excluded
Supports	- Beginning from Downskin-angle <= 45° (inside and outside) - When having instable components
Holes	- min. hole diameter = 3mm - The more complex the channel the bigger the hole diameter
Meshing components	- In general not possible - Eventually with big gap dimensions and usigng support
Efficiency	Keep component height in building space low

Printer specific-design-rules

Electron Beam Melting (EBM)

Basic material:	electricity conducting materials
Material form:	powder
Material distribution:	shaver
Way of merger:	with electron beam
Printing environment:	in vacuum
Advantage:	electron beam fissile, …
Disadvantage:	electron beam broader than laser beam, …



Printer specific-design-rules

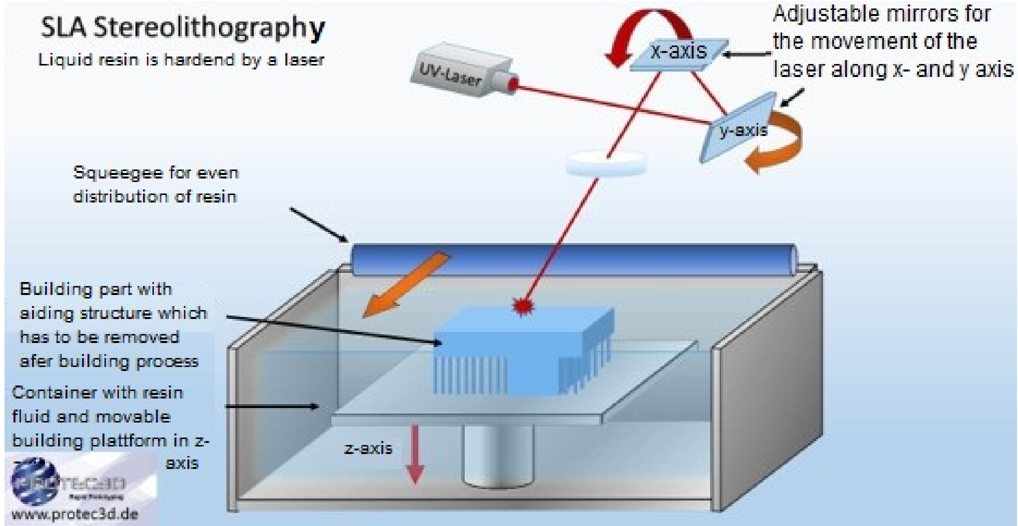
	Electron Beam Melting
Wall thickness	>= 0,6mm
Powder removal	Simple outline: One hole with D > 3mm Complex outline: Ev. more holes with D > 7mm
Spalte	- 0,3mm vertically - 0,4mm horizontally (for powder removability +0,3mm each)
Component alignment	- Overhangs in shaving direction - Thin components elongated in shaving direction - Thin components vertically to component level

	Electron Beam Melting
Anisotropy	- Lay line of force on component level
Accuracy	- ±0,3mm - ±0,5mm) - Form deviation excluded
Supports	- Beginning from Downskin-angle <= 45° (inside and outside) - When having instable components
Holes	- min. hole diameter = 0,6 vertically - min. hole diameter = 0,8 horizontally - The more complex the channel the bigger the hole diameter
Threads	- Have to be manufactured afterwards
Mashing components	- Gap between min. 0,6mm
Efficiency	Keep component height low

Printer specific-design-rules

Stereolithography (SLA) (STL)

Basic material:	materials that harden with light
Material form:	liquid
Material distribution:	wiper
Connection type:	hardening with laser
Laser alignment:	with mirror
Advantage:	precise and filigree prints, …
Disadvantage:	fluid plastic relatively expensive, …



Printer specific-design-rules (SLA / STL)

	Stereolithograpy
Wall thickness	Unsupported wall: >= 1mm Supported wall: >= 0,4mm
Liquid removal	Min. one hole with D min. 3,5mm
Holes	min. hole diameter = 0,5mm
Accuracy	Min. line thickness = 0,5mm Min. line depths = 0,5mm
Surface quality	Best surface if it is parallel or vertical to building level

	Stereolithography
Maximum horizontal support bridge	- 21mm (Form3 printer by Formlabs)
Supports	- Beginning from Downskin-angle <= 30° (inside and outside) - When having instable components - To avoid difting away of a pressure
Support-removal	If support is placed inside for removal min. one hole a minimum diameter of 10mm recommended
Meshing components	- In general not possible - Eventually with big gap dimensions and using support
Efficiency	Keep component height low

Printer specific-design-rules

Fused Deposition Modeling (FDM)

Basic material: PLA, PVA, ABS, PC, HIPS, PETG…

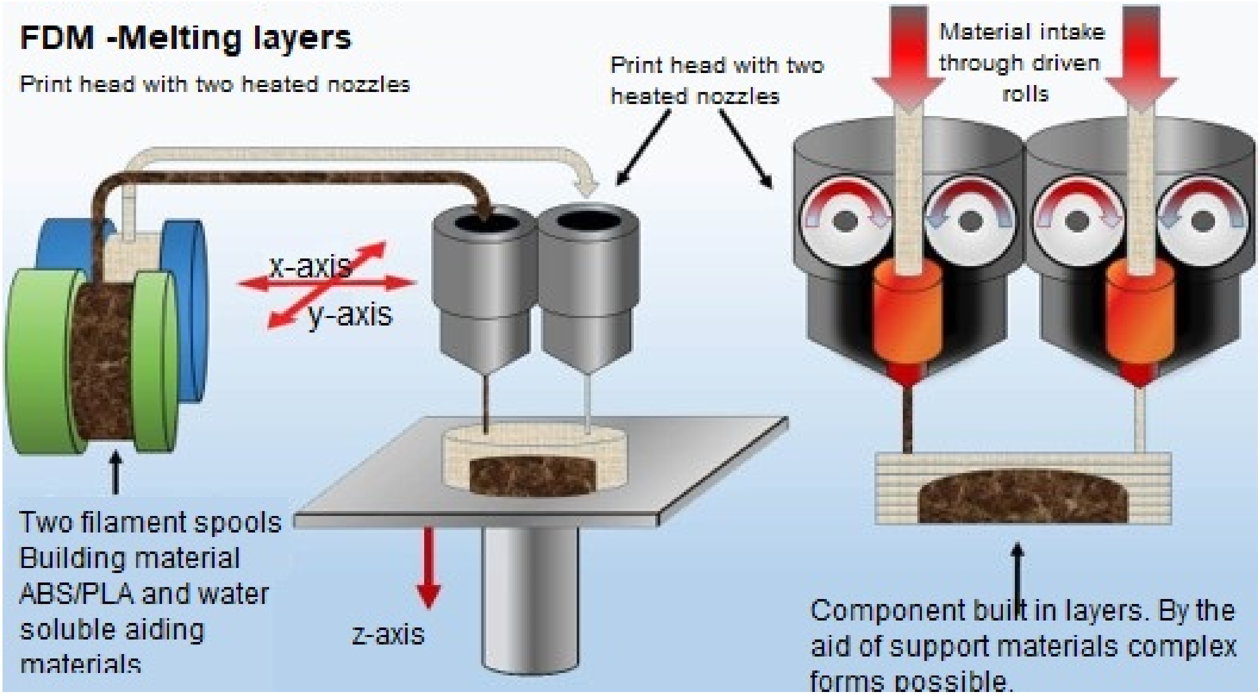
Material form: fix bar stock

Way of merger: with extruder

Nozzle positioning: with X-,Y- and Z-axis

Advantage: low cost, …

Disadvantage: anisotropy, …



Printer specific-design-rules (FDM)

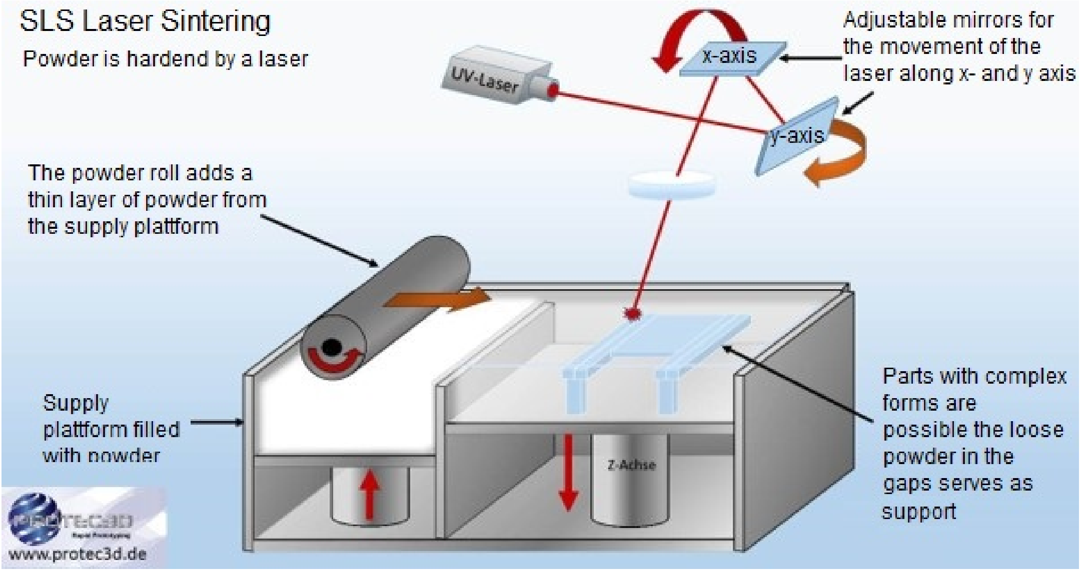
	FDM
Wall thickness	Unsupported wall: >= 1mm Supported wall: >= 0,4mm
Engraved surface details	Min. line thickness = 1mm Min. line depths = 0,3mm
Characterized surface details	Min. line thickness = 2,5mm Min. line depths = 0,5mm
Surface quality	Best surface if it is parallel or vertical to building level
Delay	Reducing delays by minimizing to print traverse (erect parts)

	Fused Deposition Modeling
Anisotropy	Lay line of force on component level
Holes	min. hole diameter = 2mm
Supports	- Beginning from Downskin-angle <= 45° (inside and outside) - When having instable components
Support-removal	- If support is placed inside for removal min. one hole a minimum diameter of 10mm recommended - Use water solublesup port material
Mashing-components	- Support material is water soluble - Recommended gap min. 0,4mm
Accuracy	- ±0,15% (minimum limit ±0,2mm) - Form deviation excluded
Efficiency	Keep component height low

Printer specific-design-rules

Laser Sintering (SLS)

Basic material:	polyamide,…
Material form:	powder
Material distribution:	powder roll
Way of merger:	with laser
Laser alignment:	with mirror
Advantage:	no support structures, …
Disadvantage:	less materials than FDM, …



Printer specific-design-rules (SLS)

	Laser Sintering
Wall thickness	Unsupported wall: >= 1mm Supported wall: >= 0,3mm
Engraved surface details	Min. line thickness = 1mm Min. line depths = 1,5mm Min. total height = 4,5mm
Characterized surface details	Min. line thickness = 0,8mm Min. line depths = 0,8mm Min. total height = 3mm
Surface quality	Best surface if it is parallel or vertical to building level

	Laser Sintering
Anisotropy	Lay line of force on component level
Holes	min. hole diameter = 1mm (with addiditional complexity of channel the hole diameter should grow)
Threads	Beginning from M10 (below too weak)
Powder removal	Min. 2 holes with D = min. 10mm
Supports	Normally not needed (Eventually only with instable components)
Accuracy	- ±0,15% (minimum limit ±0,2mm) - Form deviation excluded
Efficiency	Keep component height in building space low

Printer specific-design-rules (SLS)

	Laser Sintering
Component alignment	- Overhangs in shaving direction - Thin components elongated in shaving direction - Thin components vertically to component level
Milling	Material Polyamid (PA12) is best suited
Delay	Reducing delays by minimizing to print traverse (erect parts)

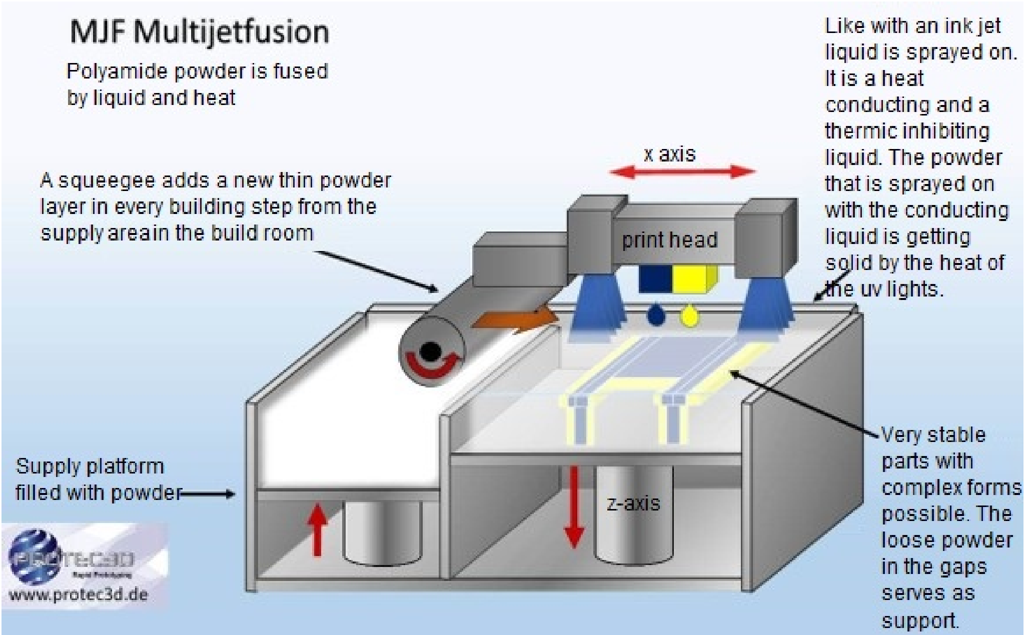
	Laser Sintering
Meshing components	- Generally possible - Recommended gap min. 0,5mm – 0,6mm
Sealing	- Improves water sealing - Better results by single outlines - Channel diameter min 6mm
Smoothing	- Do not use with small details (danger of breaking) - Rounded edges have a higher grinding grade - Consider material adding when constructing

Printer specific-design-rules

Multi Jet Fusion (MJF)

Basic material: polyamide,
Material form: powder
Material distribution: squeegee
Way of merger: with UV lamp
Aids: thermal conducting liquid

Advantage: no support structures, …
Disadvantage: less materials than FDM, …



Printer specific-design-rules (MJF)

	Multi Jet Fusion
Wall thickness	Unsupported wall: >= 1mm Supported wall: >= 0,5mm
Surface quality	- Best surfaces are downsides - Others tend to dent - Massive full bodies tend to melt surrounding powder with their residual heat
Anisotropy	Nearly no anisotropy
Holes	- min. hole diameter = 1mm - single channels min D = 2mm
Threads	Useful beginning from M10 (below too weak)

	Multi Jet Fusion
Threads	Useful beginning from M10 (below too weak)
Powder removal	min. 2 holes with D = min. 2mm or min. 1 hole with D = 5mm
Supports	Normally not needed (Ev. only with instable components)
Efficiency	Keep component height low
Meshing components	- Generally possible - Recommended gap min. 0,5mm
Delay	Reducing delays by minimizing to print traverse (erect parts)
Engraved or characterized surface details	Min. line thickness = 0,5mm Min. line depths = 1mm Min. total height = 2,5mm

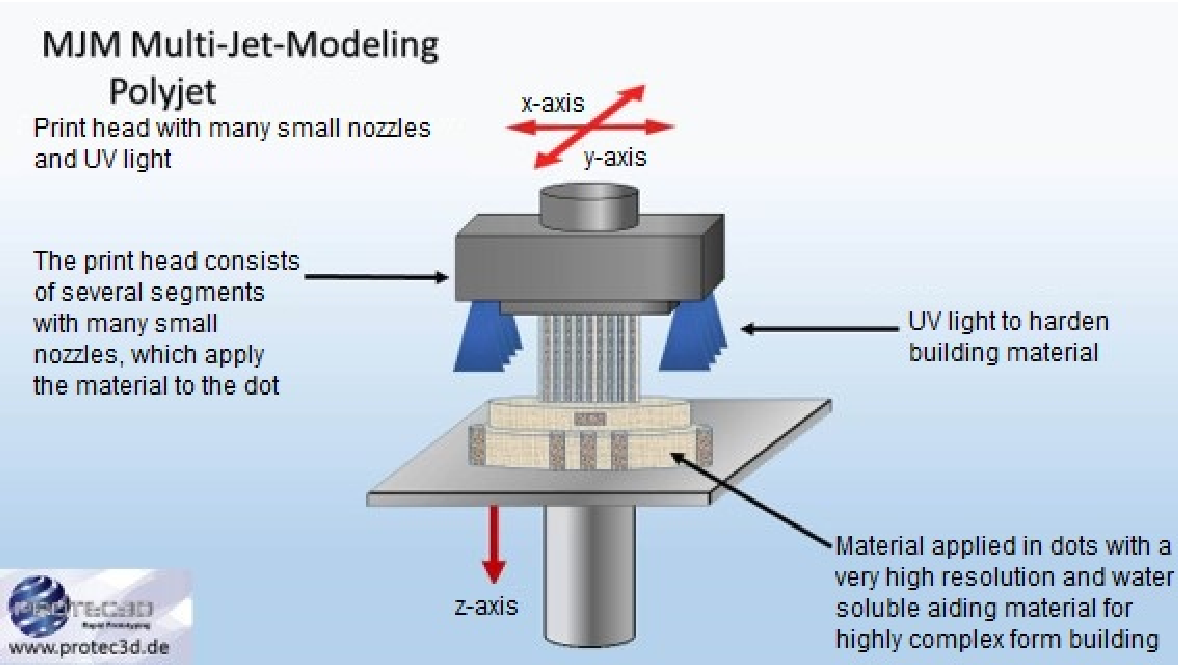
Printer specific-design-rules

Polyjet

Basic material: polymericic that becomes hard under light
Material form: liquid
Material distribution: nozzles
Way of merger: with UV-Light

Advantage: flat surface, many print heads, ,…

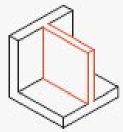
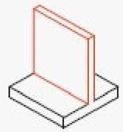
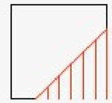
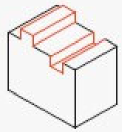
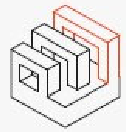
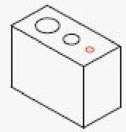
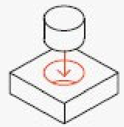
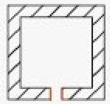
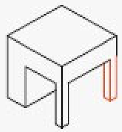
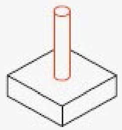
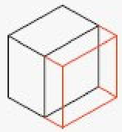
Disadvantage: less materials than FDM, …



Printer specific-design-rules (Polyjet)

	Polyjet
Wall thickness	Unsupported wall: >= 1mm Supported wall: >= 0,5mm
Dimension accuracy	±0,1mm to ±0,3mm
Meshing components	- Generally possible if support material is water soluble - Recommended gap min. 0,1 to 0,4 mm

	Polyjet
Holes	- min. hole diameter = 1mm - single channels min. D = 2mm
Liquid removal	min. 1 hole with D = 5mm
Engraved surface details	Min. line thickness = 0,5mm Min. line depths = 0,5mm
Characterized surface details	Min. line thickness = 0,8-1mm Min. line depths = 0,5mm
Surface quality	Flat surface

	Supported Walls	Unsupported Walls	Support & Overhangs	Embossed & Engraved Details	Horizontal Bridges	Holes	Connecting /Moving Parts	Escape Holes	Minimum Features	Pin Diameter	Tolerance
	Walls that are connected to the rest of the print on at least two sides.	Unsupported walls are connected to the rest of the print on less than two sides.	The maximum angle a wall can be printed at without requiring support.	Features on the model that are raised or recessed below the model surface.	The span a technology can print without the need for support.	The minimum diameter a technology can successfully print a hole.	The recommended clearance between two moving or connecting parts.	The minimum diameter of escape holes to allow for the removal of build material.	The recommended minimum size of a feature to ensure it will not fail to print.	The minimum diameter a pin can be printed at.	The expected tolerance (dimensional accuracy) of a specific technology.
											
Fused Deposition Modeling	0.8 mm	0.8 mm	45°	0.6 mm wide & 2 mm high	10 mm	Ø2 mm	0.5 mm		2 mm	3 mm	±0.5% (lower limit ±0.5 mm)
Stereo-lithography	0.5 mm	1 mm	support always required	0.4 mm wide & high		Ø0.5 mm	0.5 mm	4 mm	0.2 mm	0.5 mm	±0.5% (lower limit ±0.15 mm)
Selective Laser Sintering	0.7 mm			1 mm wide & high		Ø1.5 mm	0.3 mm for moving parts & 0.1 mm for connections	5 mm	0.8 mm	0.8 mm	±0.3% (lower limit ±0.3 mm)
Material Jetting	1 mm	1 mm	support always required	0.5 mm wide & high		Ø0.5 mm	0.2 mm		0.5 mm	0.5 mm	±0.1 mm
Binder Jetting	2 mm	3 mm		0.5 mm wide & high		Ø1.5 mm		5 mm	2 mm	2 mm	±0.2 mm for metal & ±0.3 mm for sand
Direct Metal Laser Sintering	0.4 mm	0.5 mm	support always required	0.1 mm wide & high	2 mm	Ø1.5 mm		5 mm	0.6 mm	1 mm	±0.1 mm