ESCOLA POLITÉCNICA DA UNIVERSIDADE DE SÃO PAULO

PMR 3301

Complementos de Fabricação Mecânica

Profa. Izabel Machado

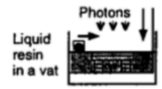
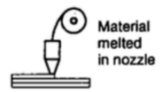
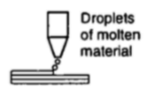
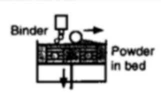
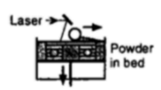
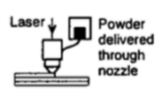
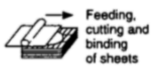
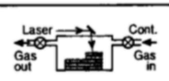
Table 2: *Most successful industrial RP systems*

Process	Vendor sales in 1997
Stereo-Lithography (SL) 281 units (26%)	3D Systems: 165 units (16%)
	Japanese vendors: 97units (9%)
	EOS-Stereos: 22 units (2%)
Fused Dep. Mod. (FDM) (25%)	Stratasys: 260 units (25%)
Ink Jet Printing (IJP) 265 units (26%)	Sanders: 152 units (14%)
	3D Systems: 113 units (11%)
Laminated Object Mfg. (LOM) 98 units (9%) [162 units (15%)]	Helysis: 76 units (7%)
	Kira: 20 units (2%)
	Kinergy: >2 units
	[Schroff: 64 units (4%)]
Selective Laser Sintering (SLS) 75 units (7%)	DTM: 42 units (4%)
	EOSint: 33 units (3%)

Progress in Additive Manufacturing and Rapid Prototyping J.-P. Kruth (I),Katholieke Universiteit Leuven, Division PMA, Belgium M.C.Leu* (2),New Jersey Institute ofT echnolgy, Mech.Eng.Dept., USAT. Nakagawa (I),University of **Tokyo,** Inst.of Industrial Science, Japan* On leave as Program Director for Manufacturing Machines and Equipment at NSF, USA

Annals *of* the *CIRP* Vol. ***47/2/799***

Table 3: *List of industrial additive manufacturing processes*

Supply	Process	Lay-out	Layer creation technique	Phase Change during layer solidification	Materials	Variants /Laser based	Systems
L I Q U I D	**Stereo-Lithography (SL)**		Liquid layer deposition	Photo-polymerization	Photo-polymers: - acrylates - epoxies - filled resins (glass, ceramic, metal,...) - colorable resins	Laser illumination	3D System - SLA (US) NTT Data CMET-SOUP (J) D-MEC/Sony - SCS (J) [EOS - Stereos (D)][2] MEIKO-Colamm (J) Teijin Seiki (Dupont)-Soliform (J) Aaroflex (Dupont) - Solid Imager Denken - SLP (J) (US) Fockele & Schwarze (D) Ushio – Unirapid (J)
						Flash lamp + milling layers	Cubital - SCG (Isr)
	Fused Deposition Modeling (FDM)		Continuous extrusion and deposition	Solidification by cooling	Polymers: (ABS, PA,...) Wax Filled polymers (glass,...)	FDM	Stratasys - FDM (US) Stratasys - Genisys (US)
					Metals with binder	MJS	Development [IFAM (D)]
					Ceramics with binder	FDC	Development [Austin, Rutgers]
	Ink Jet Printing (IJP)		Drop-on-demand deposition	Solidification by cooling	Polymers Wax		3D System - Actua (US)
						milling layers	Sanders - ModelMaker (US)
						5-axis milling layer +contour	Development [Stanford]
P O W D E R	**Three Dimensional Printing (3D-P)**		Layer of powder + Drop-on-demand binder printing	No phase change	Ceramics with binder		Soligen-DSPC (US)
					Metals with binder		Extruhone-3DP (US)
					Polymer with binder		Z-corp.-3DP (US)
	Selective Laser Sintering (SLS)		Layer of powder	Laser sintering / Laser melting & resodification by cooling	Polymers (PC, PA,...) Filled polymers (glass,...) Metals with binder Metals (pure) Sand, ceramics	Laser-based	DTM - Sinterstation (US) EOS - EOSint (D)
	Laser Cladding		Continuous injection of powder	Laser melting & solidification by cooling	Metals	Laser + milling layer and contour	Röders - CMB (D)
						Laser-based	Development: - LENS [Sandia] - LAPS-J [IPK (D)]
S O L I D	**Laminated Object Manufactur. (LOM)**		Deposition of sheet material	No phase change	Paper	Laser cutting	Helisys-LOM (US) Kinergy-ZIPPY (Sing.)
						Knife cutting	Kira - SAHP (J)
					Polymer	Knife cutting	[SPARX-(Sweden)][2]
					Polymer foam	Heated wire cutting	Development [Utah]
					Composites	Laser cutting	Helisys-LOM (US)
					Ceramics	Laser cutting	Development [Dayton]
					Metals	Laser cutting	Semi-industrial [U. Tokyo, U. Erlangen (D), CRIF(B)]
G A S	**Selective Laser Chem. Vapour Deposition**		Condensation of gas	Forming solid from gas by chemical reaction	Metals (Al, FeNi,...) Ceramics (SiC,...)	Laser-based	Development: - LCVD [M. Planck-(D)] - SALD [Connect., Texas, Rensselaer.]

[2]Activity ceased recently

Como a manufatura aditiva mudou os modelos de negócios

Table 1
Feasibility issues between additive and conventional manufacturing processes, summarized from [1,10,15,17,18,22,30,31,34–39].

Issue	Additive	Conventional
Market segment	High margin, niche segments with high customization and relatively low economic potential of product	Low margin, mass segments with low customization and high economies of scale
Demand and supply chain	Uncertain / unitary demand, which is best matched with engineering to order deliveries; high order fulfillment requirements; and/or high relative transportation costs versus product value	Stable / uncertain demand, when products can be made stock and shipped with negligible costs relative to product value
Intellectual Property Rights (IPR) status	Expired / un-patented / un-branded products with low standardization requirements	Highly branded products (= mass market) with established standards and patents
Production process	Low level of automation with a high number of distinct production phases that AM can integrate	High level of automation and a limited number of process phases
Product characteristics	Small products with highly complex structures; flexible product quality requirements in terms of finishing, strength, etc.	Products of any size with maximum quality required
Raw material type	Expensive, primarily synthetic powders that in solid form have low machinability and/or high material removal rate	Low to high cost, organic or synthetic materials that have good machinability and naturally occur in solid form to be used in subtractive processes

How Additive Manufacturing Technology Changes Business Models? – Review of Literature , Additive Manufacturing 32 (2020) 101070
Jyrki Savolainen, Mikael Collan

Como a manufatura aditiva mudou os modelos de negócios

J. Savolainen and M. Collan *Additive Manufacturing 32 (2020) 101070*

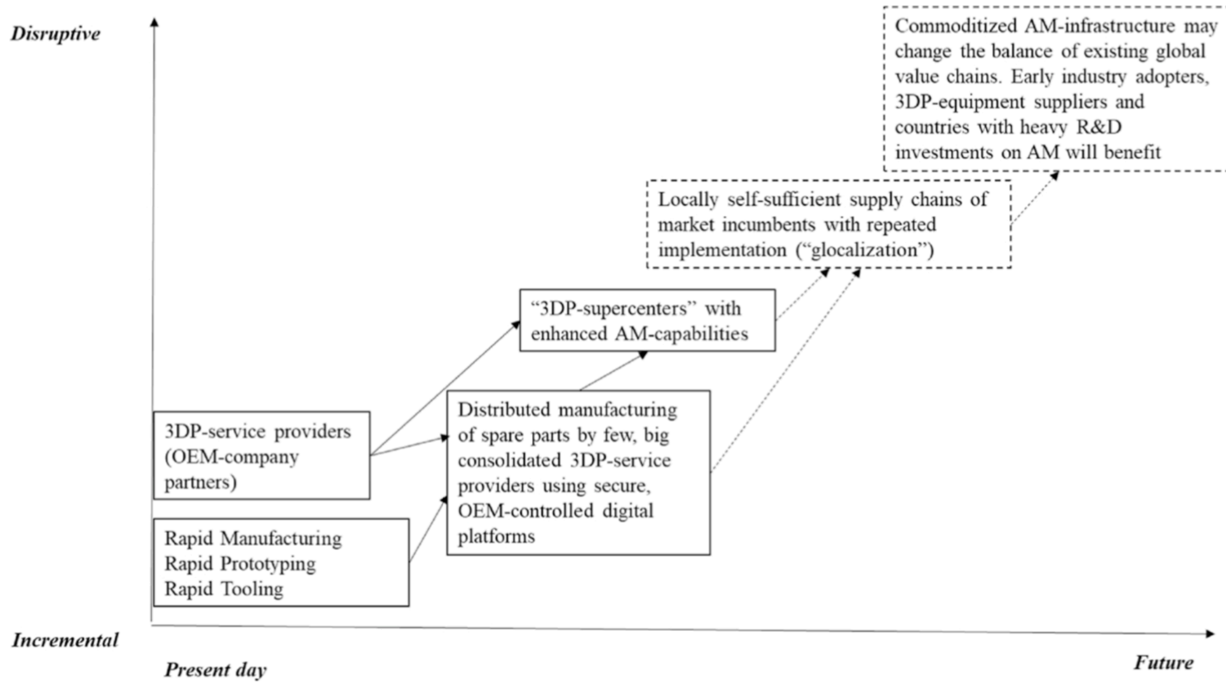


Fig. 3. Main directions within the closed BM-paradigm, where dashed lines represent the less probable direction of development in the near future.

How Additive Manufacturing Technology Changes Business Models? – Review of Literature , Additive Manufacturing 32 (2020) 101070
Jyrki Savolainen, Mikael Collan

Como a manufatura aditiva mudou os modelos de negócios

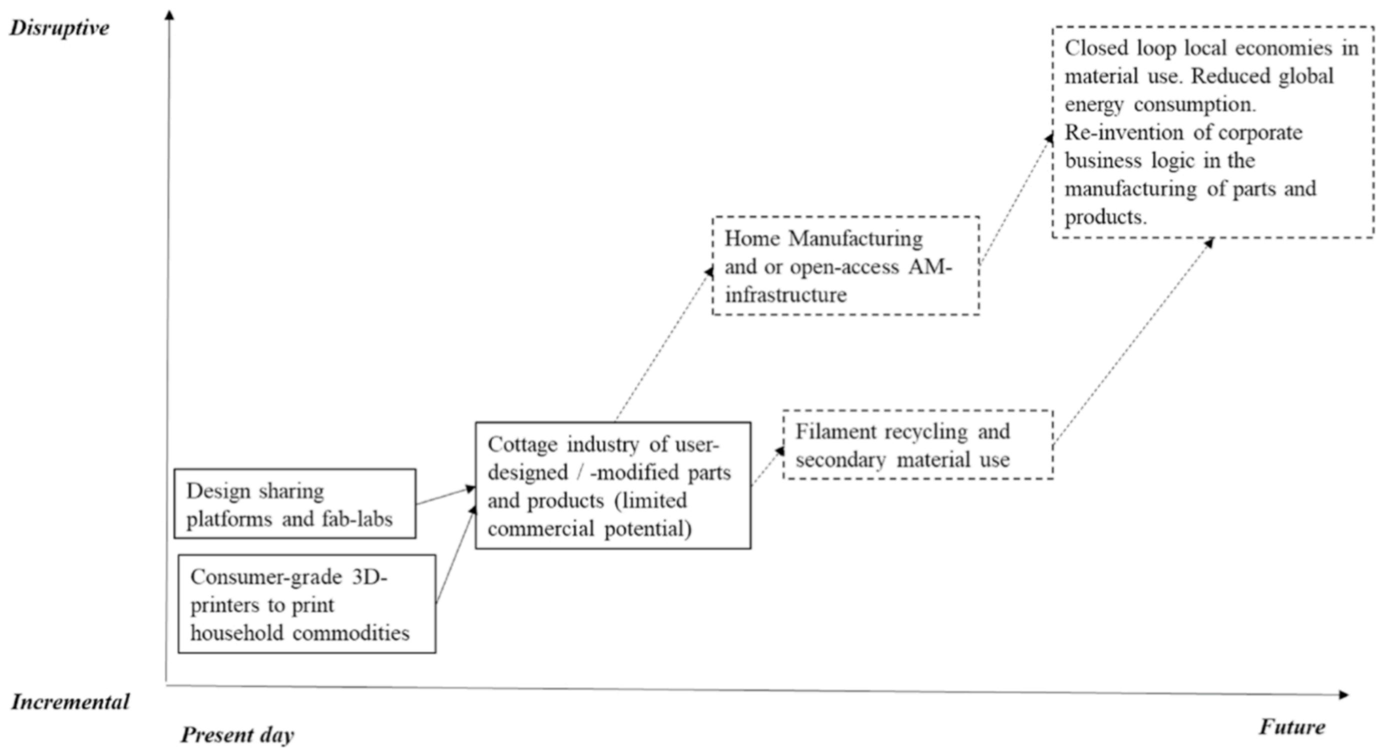


Fig. 4. Main directions within the open BM-paradigm. Dashed line indicates the improbable phases in the development.

How Additive Manufacturing Technology Changes Business Models? – Review of Literature , Additive Manufacturing 32 (2020) 101070
Jyrki Savolainen, Mikael Collan

Manufatura aditiva

Prototipagem rápida :

- ✓ CNC - Fabricação de Modelos e Moldes
- ✓ Injeção

Processamento por Injeção tem por objetivo moldar uma peça plástica com **formatos variados e complexos** com alta tolerância dimensional, forçando ao material sob pressão dentro de uma cavidade.

Industria de Moldes : http://moldesinjecaoplasticos.com.br/prototipagem-rapida-ou-manufatura-aditiva/

Prototipagem rápida : podem ser considerados com um conjunto de processos que permitem obter objetos utilizando ferramentas computacionais – modelo computacional, equipamento CNC – protótipo.

Obter um produto que permita sua visualização e melhoria do projeto antes da manufatura em grande escala

https://www.youtube.com/watch?v=JVlBcF7sXZ0 (SME)
https://www.youtube.com/watch?v=OhNnKTaciVI
https://www.youtube.com/watch?v=JMjozqJS44M
https://www.youtube.com/watch?v=fzBRYsiyxjI
https://www.youtube.com/watch?v=g-gGeAe-PJA

Manufatura aditiva

Projetos para manufatura aditiva (DfAM)

O DFM (Design for Manufacturing), que agrega os princípios a serem utilizados na fase de projeto, e que facilitam o processo de fabricação dos produtos;

O DFA (Design for Assembly), que engloba os princípios a serem utilizados na fase de projeto do produto, que facilitam sua montagem;

O DFM faz parte da metodologia DFMA (Design For Manufacturing and Assembly), composta também pela técnica DFA (Design de Montagem), sendo as duas essenciais para que os produtos sejam projetados, fabricados e comercializados em um período curto.

CIRP Annals - Manufacturing Technology 65 (2016) 737–760
http://dx.doi.org/10.1016/j.cirp.2016.05.004

DfAM

Referência: CIRP Annals - Manufacturing Technology 65 (2016) 737–760
http://dx.doi.org/10.1016/j.cirp.2016.05.004

Oportunidades, desafios e considerações econômicas

A Manufatura aditiva permite obter objetos com base na informação digitalizada de pedaço por pedaço, linha por linha, superfície por superfície, camada por camada.

Isto determina simultaneamente a geometria do objeto e propriedades do material

O dataflow manufatura aditiva mostra a sequencia de instruções para a máquina de manufatura aditiva, que dá a sequencia para a transformação da matéria prima nas partes finais

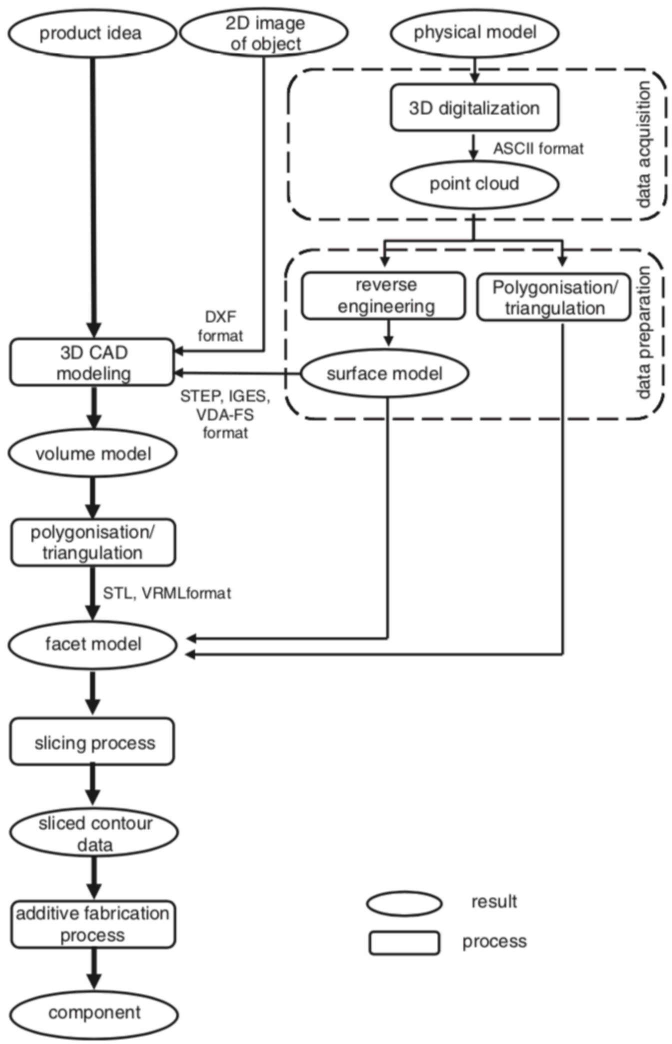
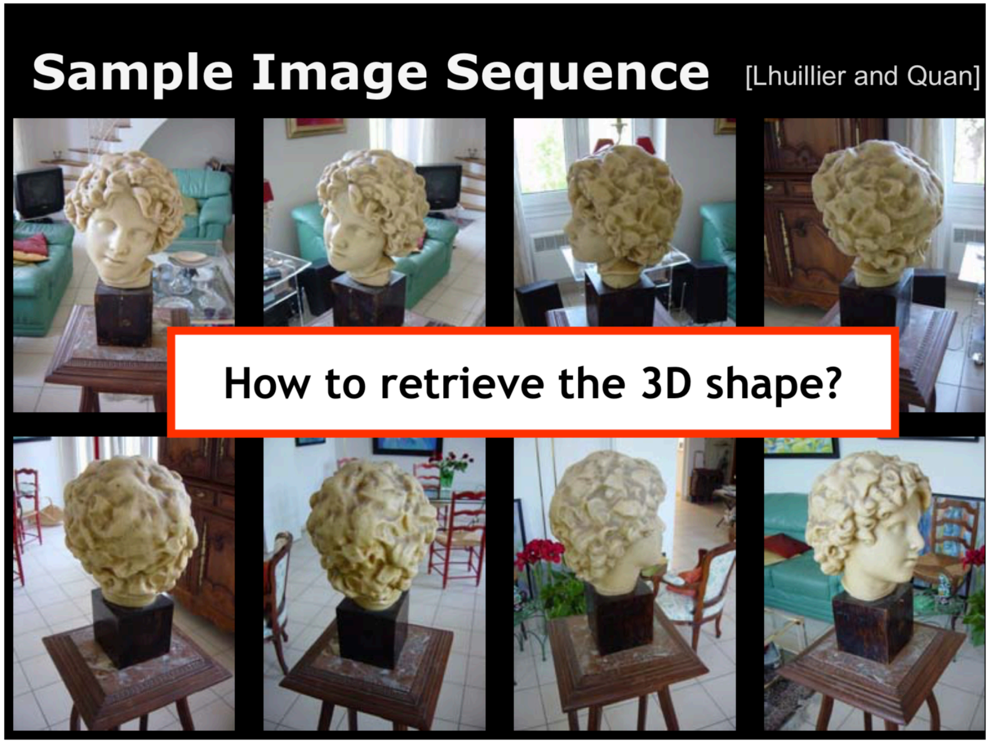
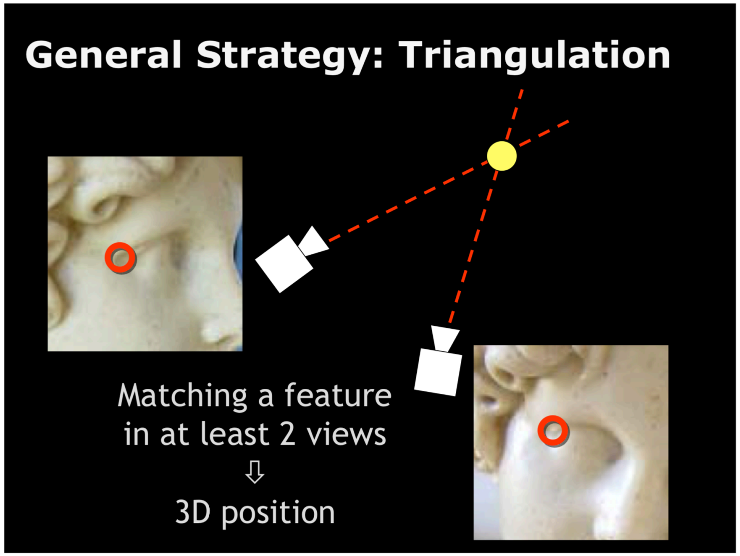
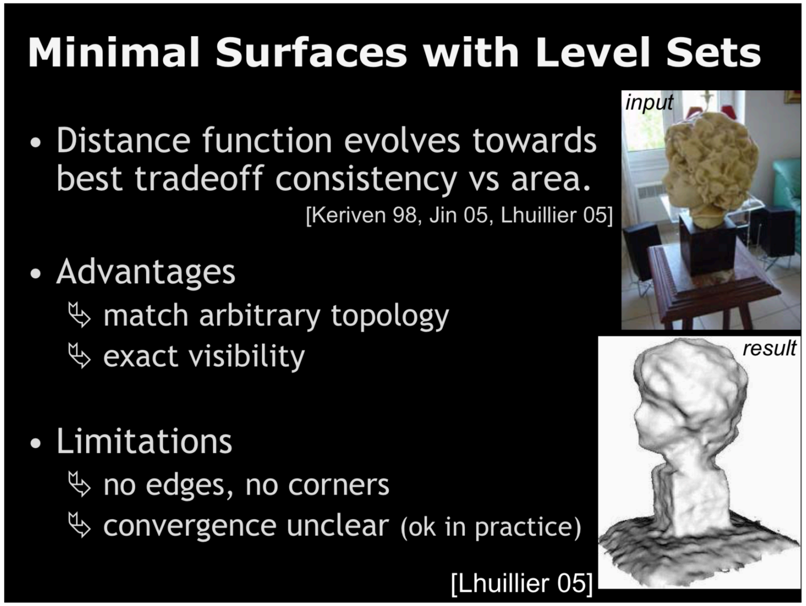


Fig. 1. Digital and physical workflow from product idea to actual component. Redrawn from [337].

Reconstrução – projeto 3D

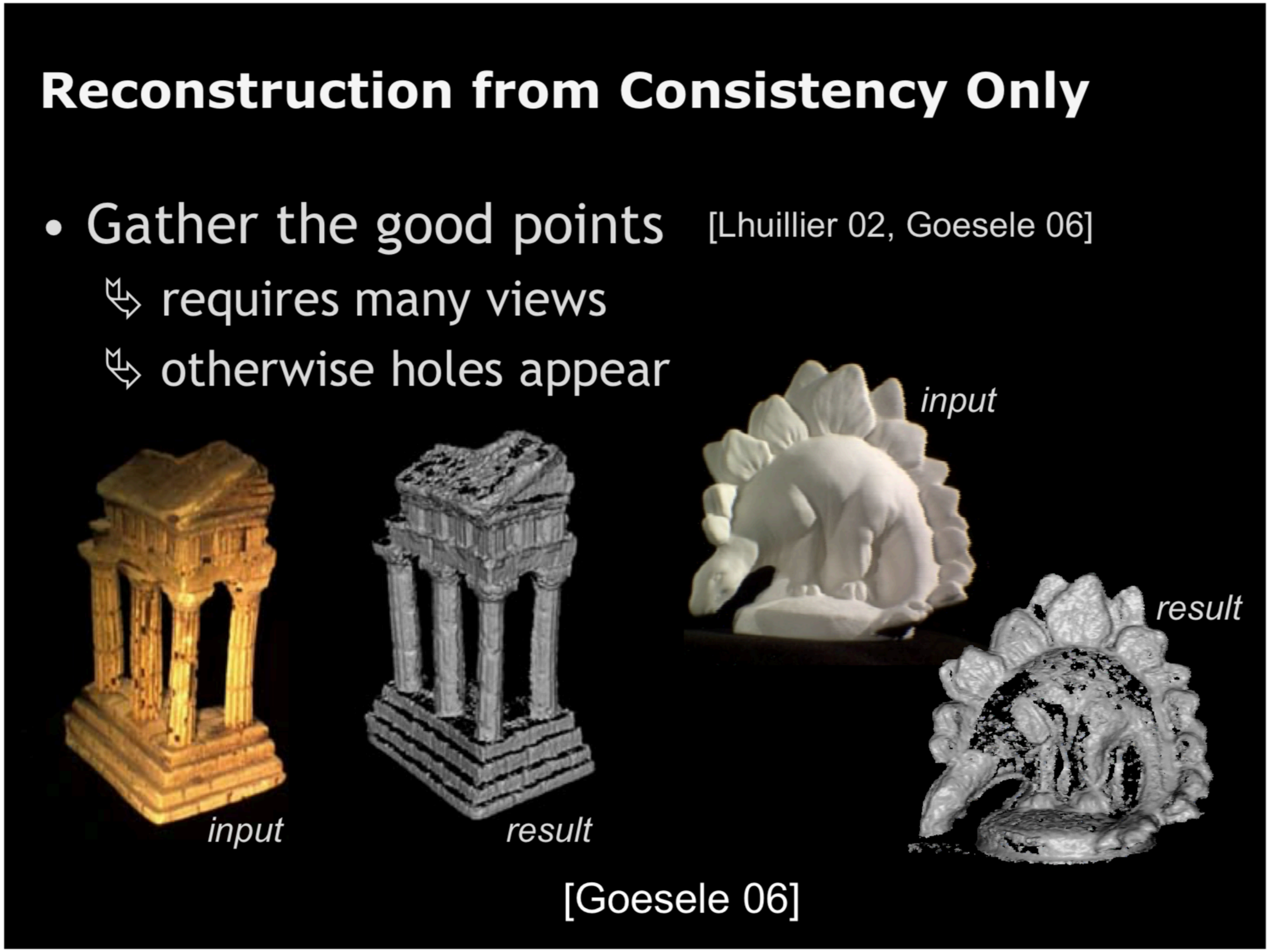






https://people.csail.mit.edu/sparis/talks/Paris_06_3D_Reconstruction.pdf

Reconstrução – projeto 3D



https://people.csail.mit.edu/sparis/talks/Paris_06_3D_Reconstruction.pdf

Reconstrução – projeto 3D – Microescala

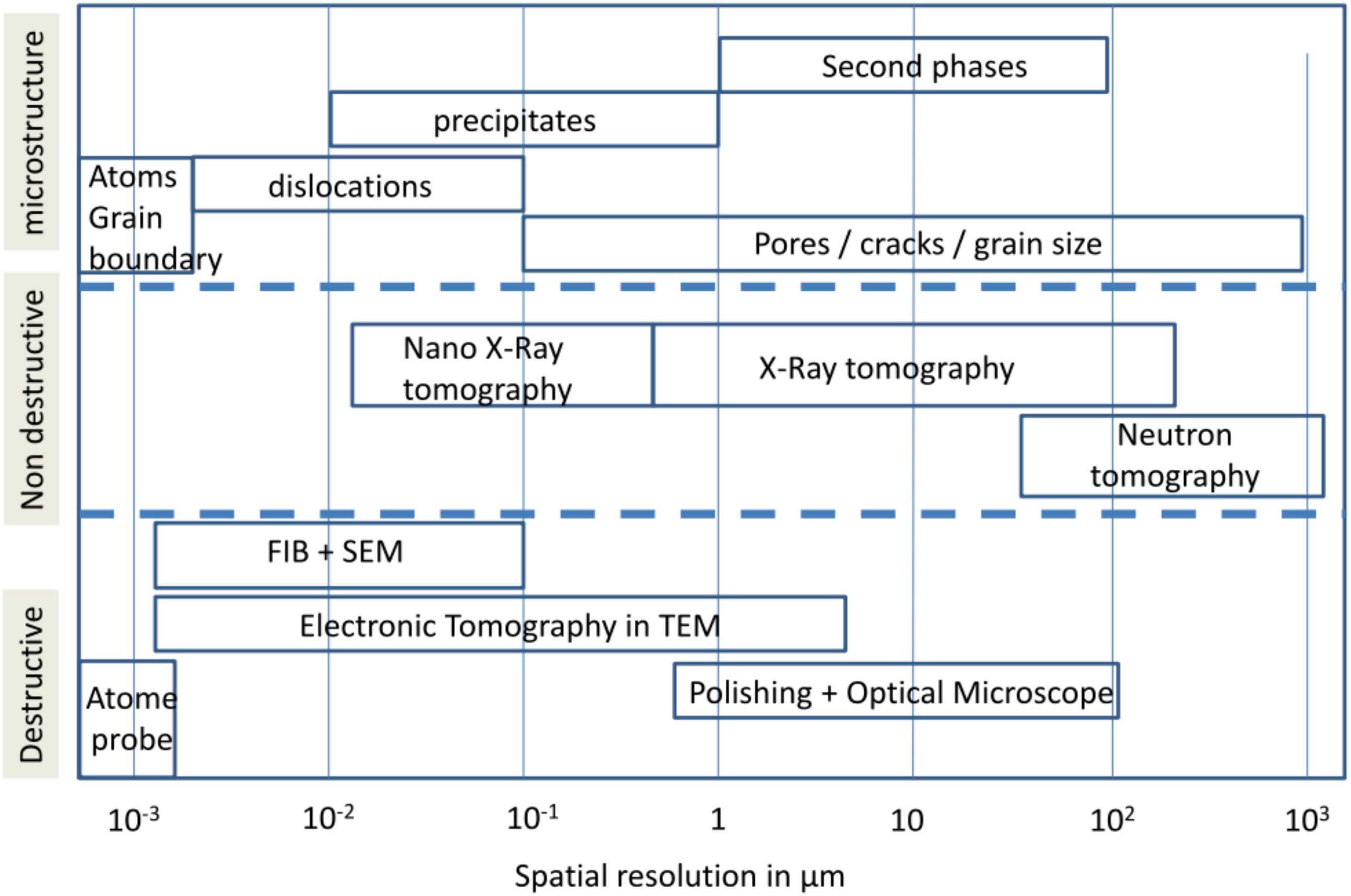


Fig. 1. Some 3D tools for 3D imaging in materials: non-destructive character and approximate spatial resolution.

http://dx.doi.org/10.1016/j.crhy.2010.12.003

Reconstrução – projeto 3D

L. Salvo et al. / C. R. Physique 11 (2010) 641–649

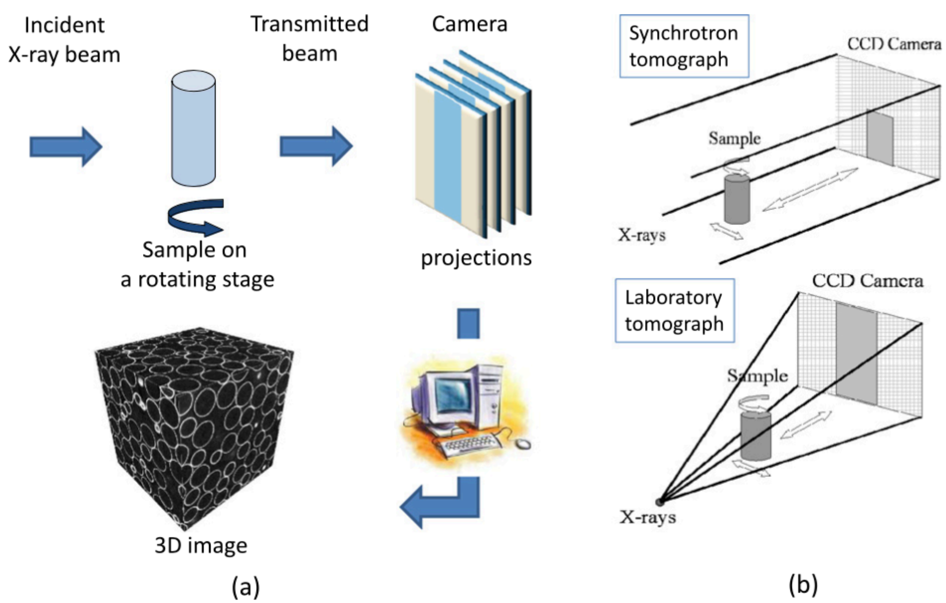


Fig. 2. (a) Principle of tomography; (b) Synchrotron and laboratory tomograph.

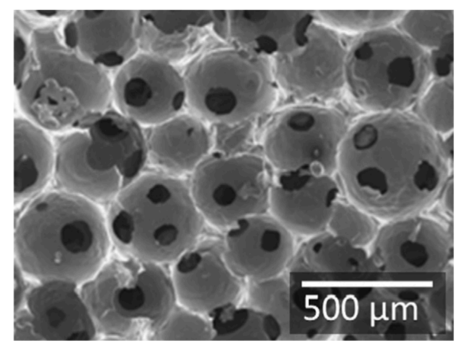


Fig. 5. SEM image of a replicated foam.

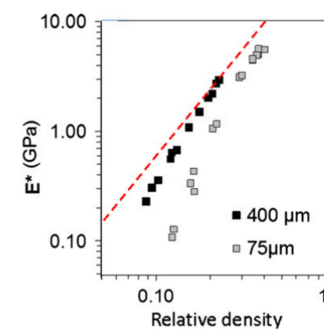


Fig. 6. Young's modulus versus relative density for two kind of replicated foams: dotted line represents Eq. (1).

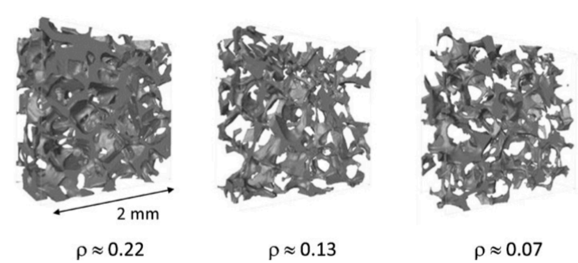


Fig. 7. 3D rendering of a 400 µm replicated foam for various relative densities.

http://dx.doi.org/10.1016/j.crhy.2010.12.003

Reconstrução – projeto 3D

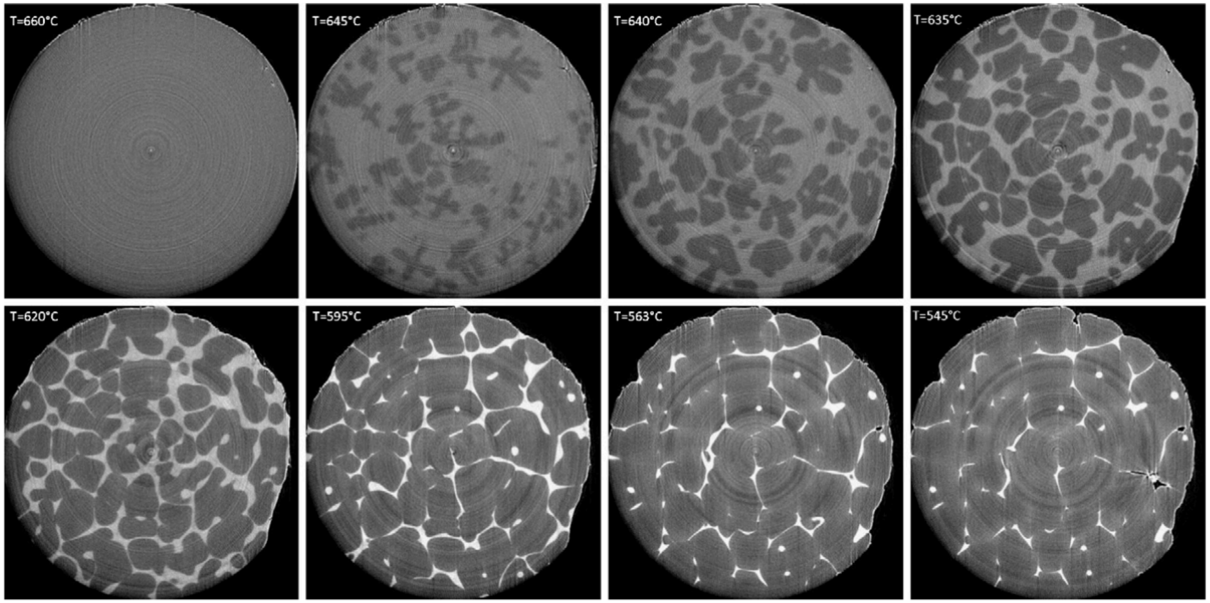


Fig. 11. 2D section of the solidification of an Al–4%Cu as a function of temperature: the diameter of the sample is 1.5 mm.

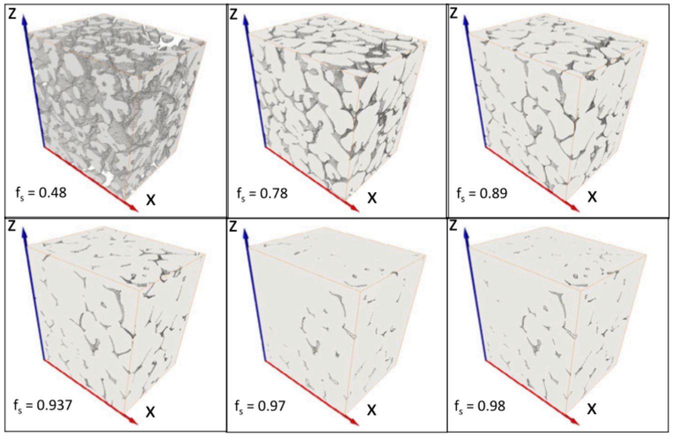


Fig. 12. 3D rendering of the solid phase as the solidification proceed (i.e. for various solid fraction): the height of the box is approximately 1.2 mm.

http://dx.doi.org/10.1016/j.crhy.2010.12.003

Reconstrução – projeto 3D

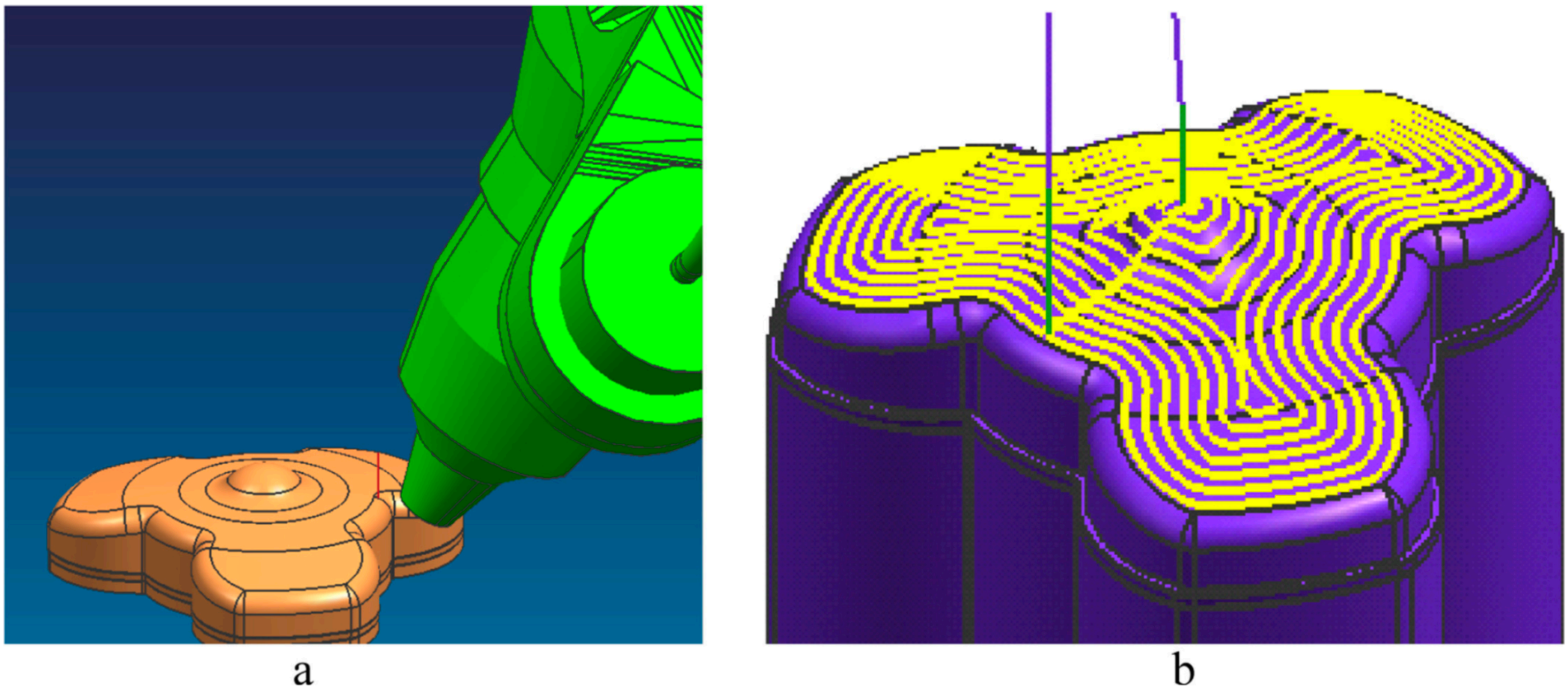


FIGURE 3

(a) CAD model of the part and process head. (b) Simulated toolpath for 5-axis deposition using DMDCAM software. Courtesy: DM3D Technology.

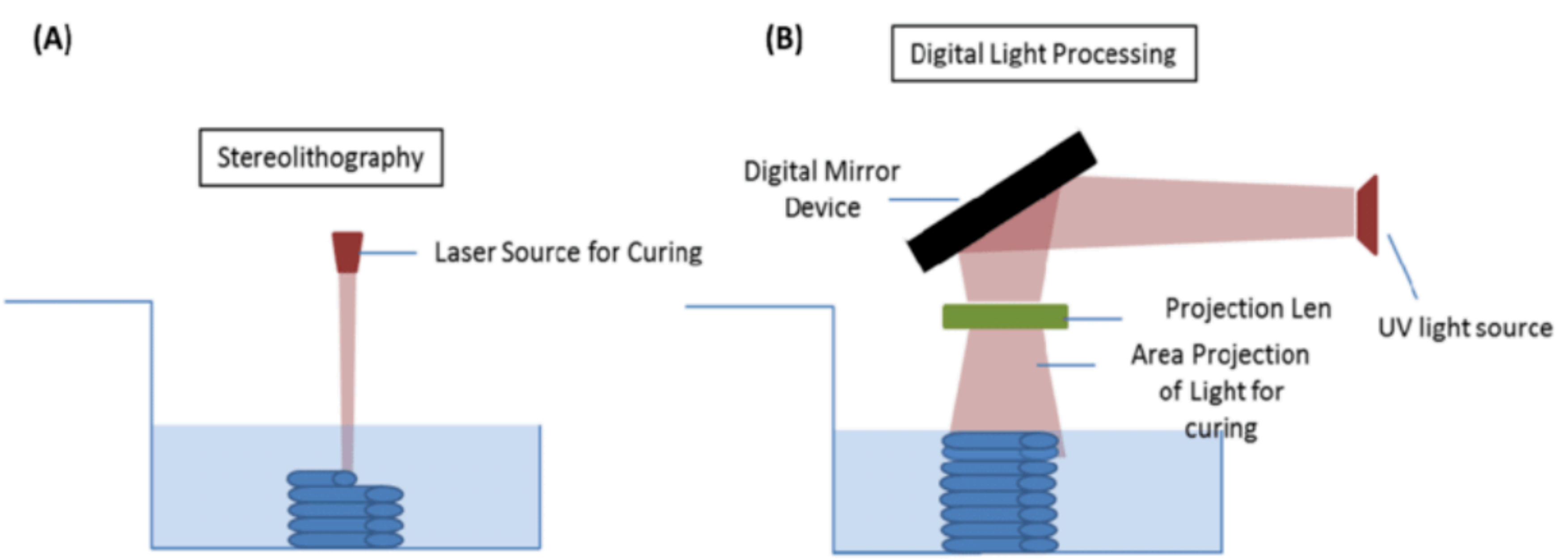
http://dx.doi.org/10.1016/j.mprp.2016.12.062

O desenvolvimento do produto segue os 7 reconhecidos grupos de tecnologia de Manufatura aditiva : binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination, and vat polymerization

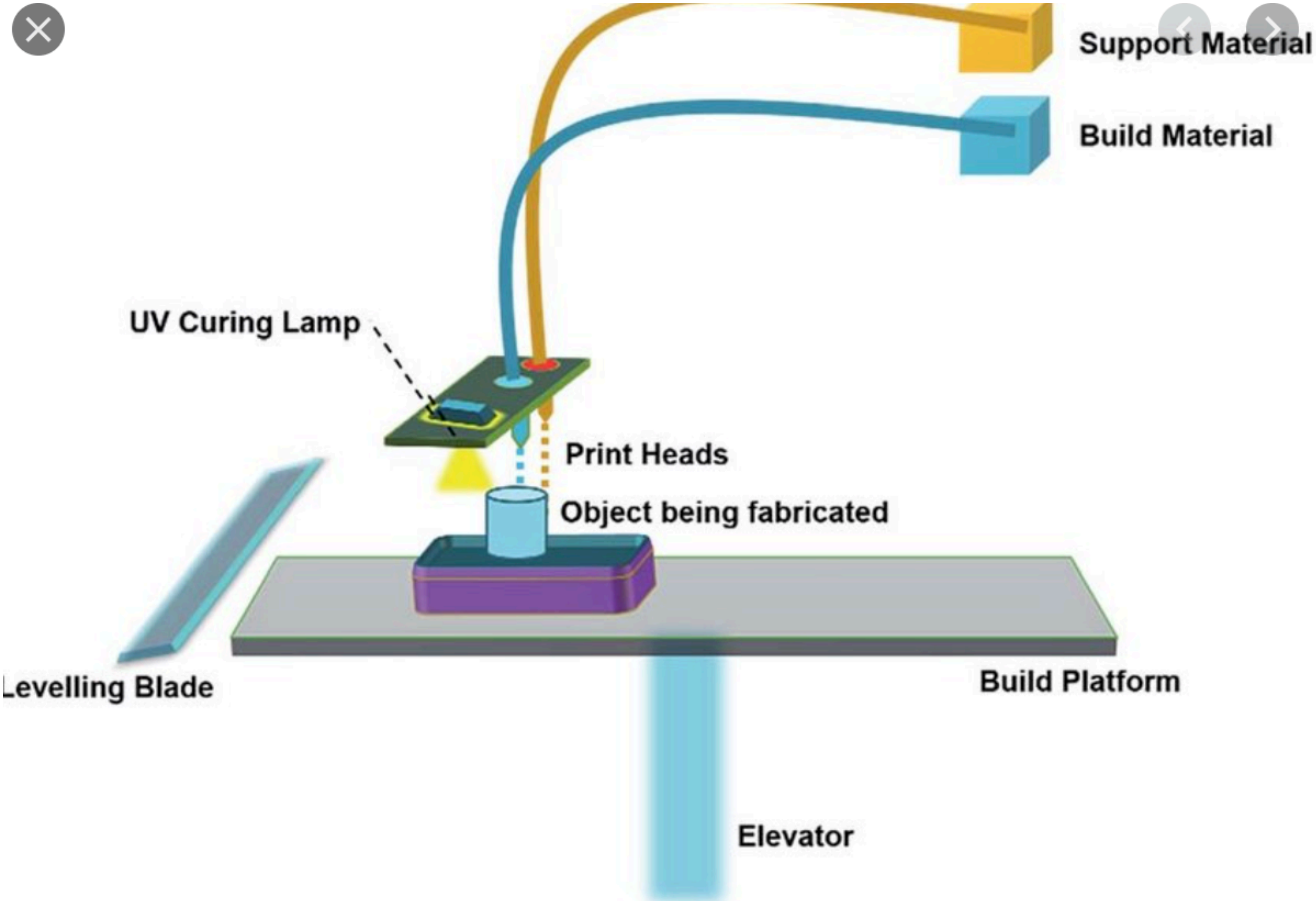
Materials	Example materials	Process categories						
		Vat photo-polymer-ization	Material jetting	Binder jetting	Powder bed fusion	Material extrusion	Directed energy deposition	Sheet lamination
Thermoset Polymers	Epoxies and acrylates	X	X					
Thermo-plastic polymers	Polyamide, ABS, PPSF		X	X	X	X		X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

Fig. 2. Additive Manufacturing process families and materials [155].

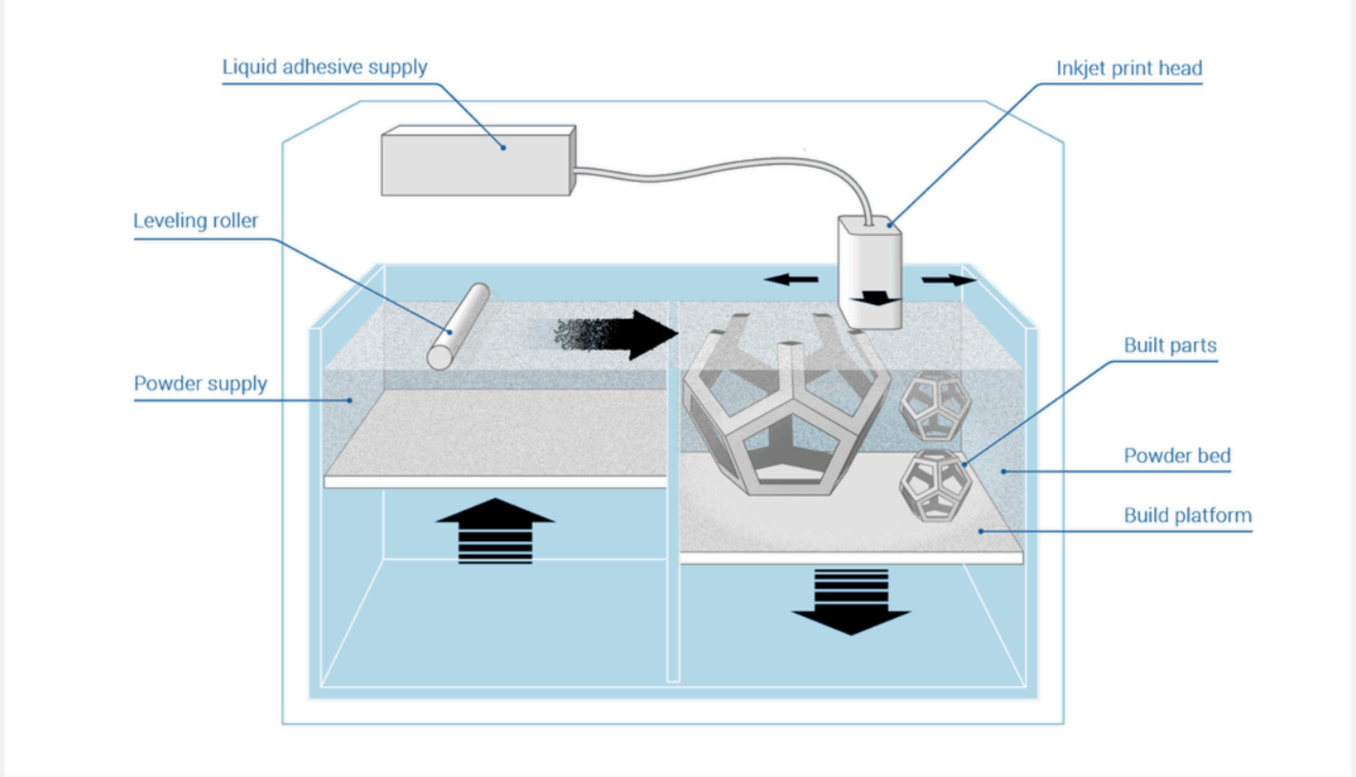
Vat Polymerization



Material Jetting

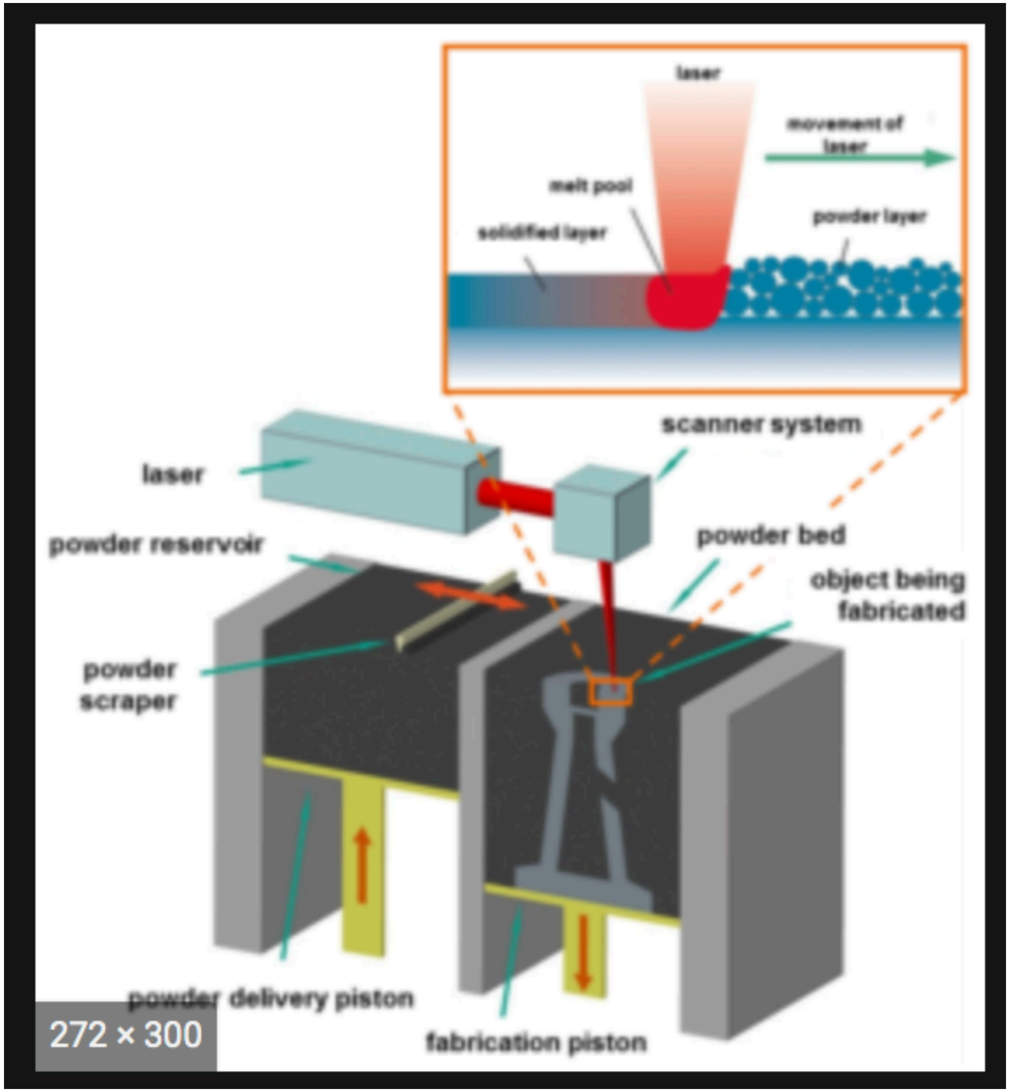


https://www.youtube.com/watch?v=RNNxEoXuvuw – Binder jetting



Binder Jetting Process

https://www.youtube.com/watch?v=te9OaSZ0kf8 Powder bed fusion



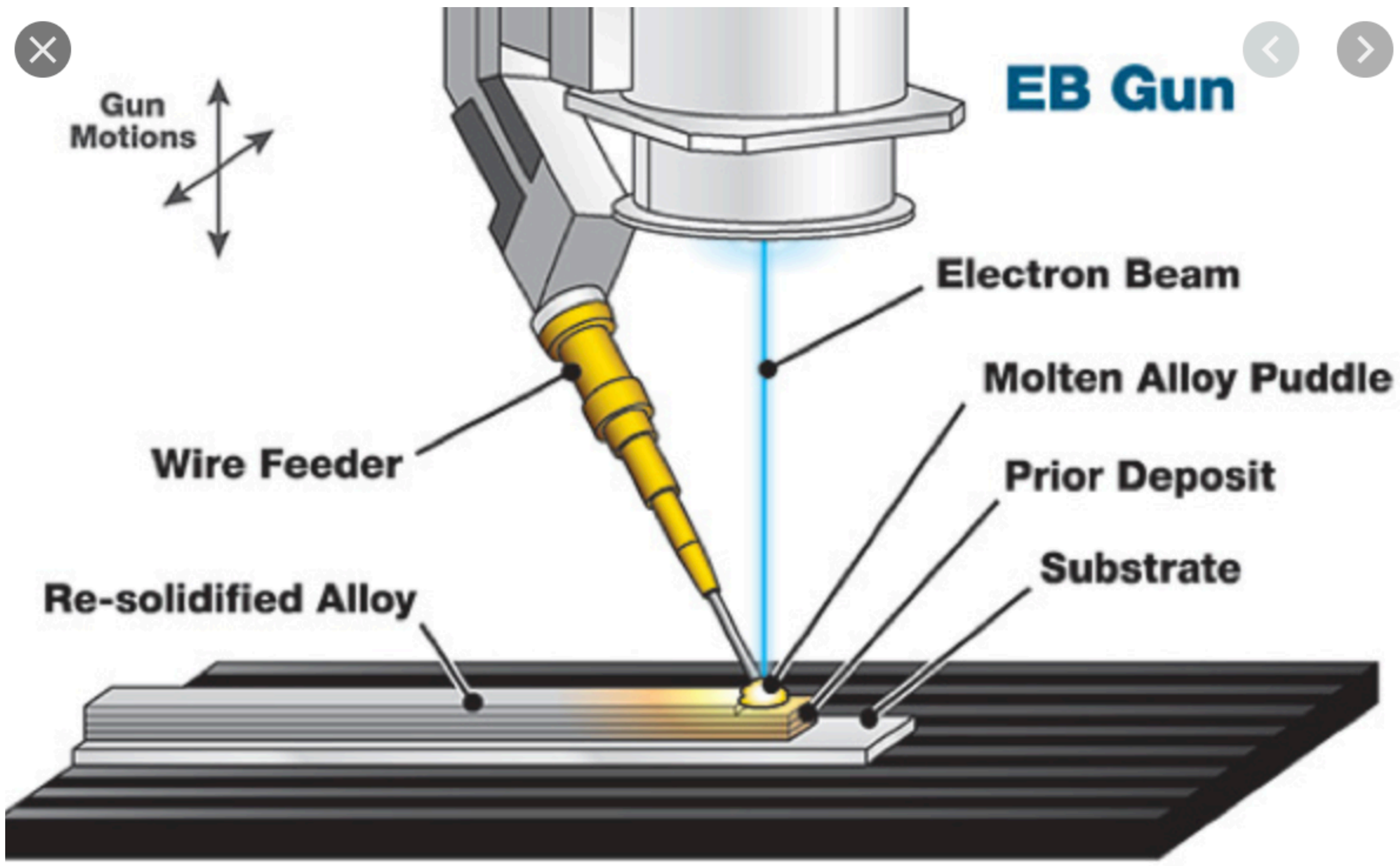
https://www.youtube.com/watch?v=VQR_Q8_KhCs

https://www.youtube.com/watch?v=x4ibQI1M1K0

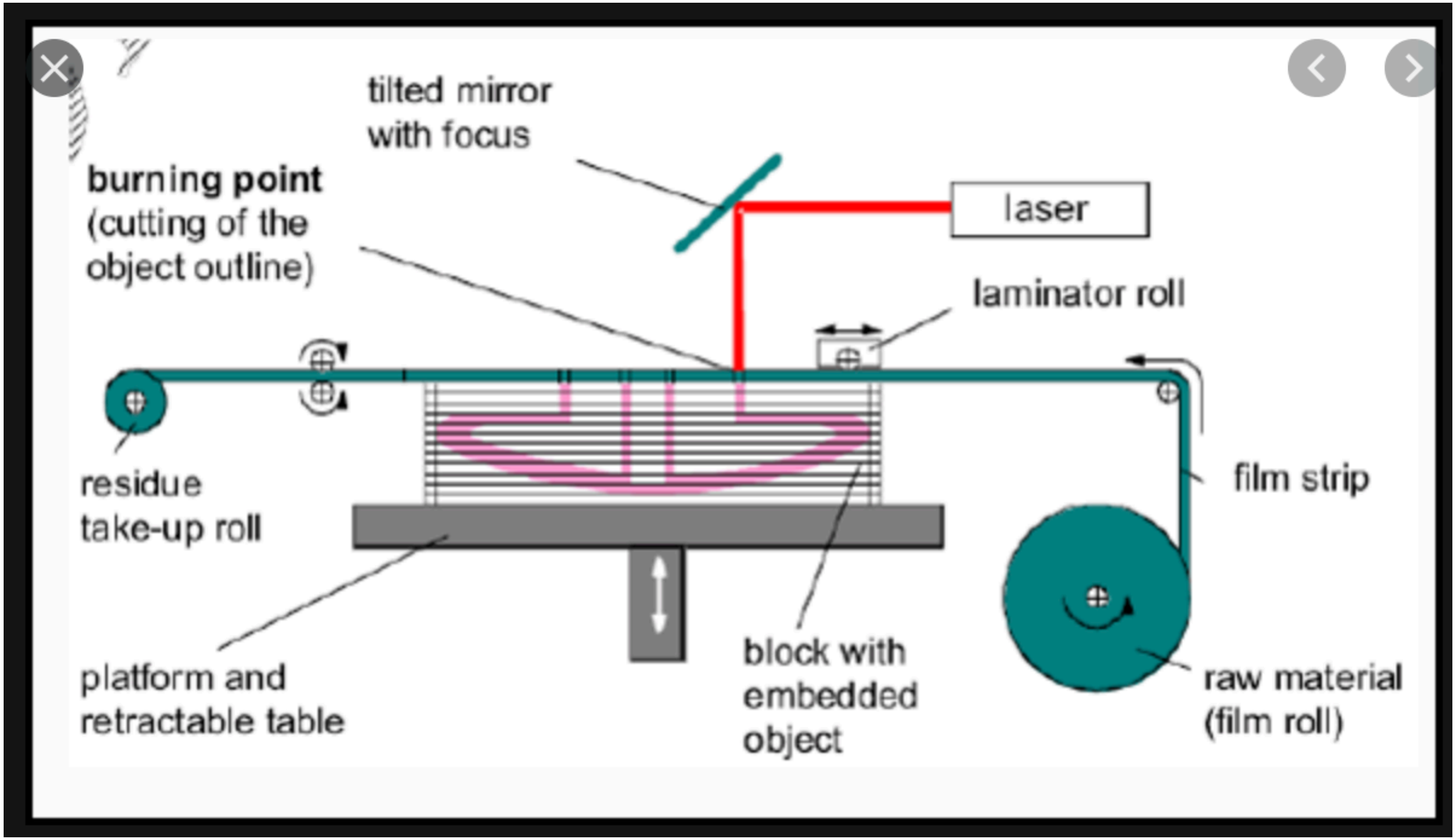
https://www.youtube.com/watch?v=LvGKfevdf_Q

Material extrusion-based additive manufacturing

https://www.youtube.com/watch?v=7kbMyt3IM3Y – Directly Energy Deposition



https://www.youtube.com/watch?v=ciCxNgROtm4 – Sheet Lamination



As partes podem ser obtidas por manufatura aditiva e usinadas (ajustes geométricos, acabamento e tolerâncias)

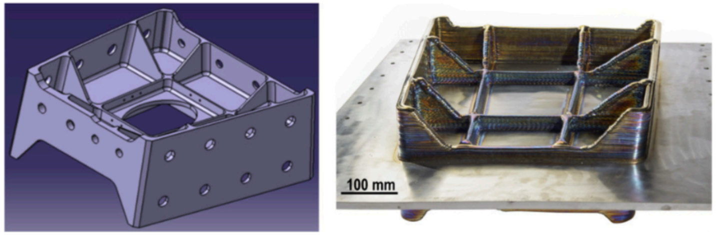


Fig. 3. Outboard landing gear rib (24 kg) produced in Ti–6Al–4V by Wire + Arc Additive Manufacturing (WAAM): CAD model (left, courtesy of the Welding Engineering and Laser Processing Centre at Cranfield University) and printed part before machining (right, [352]).

Moldes são exemplos, onde ocorre usinagem posterior.

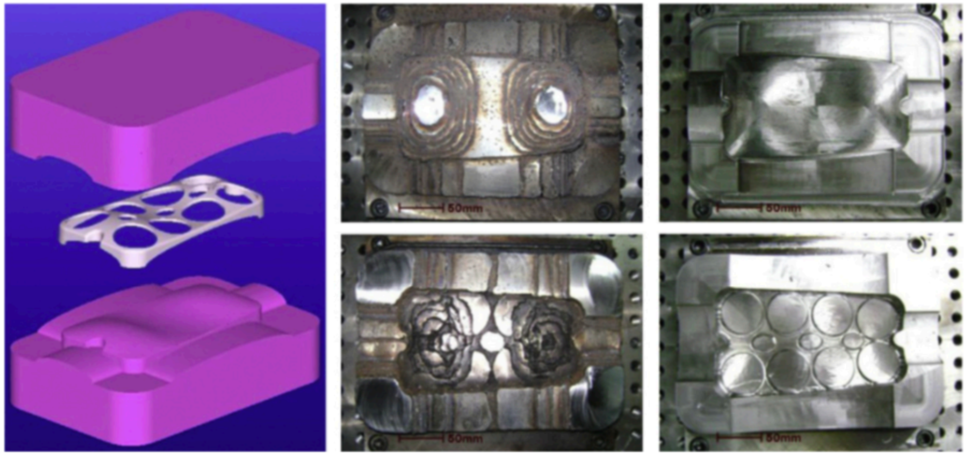


Fig. 4. Injection molding tooling produced by 3-axis Hybrid Layered Manufacturing (Gas Metal Arc Welding plus CNC machining): CAD model (left), near net shape molds (center), and finished molds (right) [317].

Outro aspecto é a impressão nos componentes e componentes que são envoltos com as Partes produzidas por manufatura aditiva

Cada família de processo tem suas características específicas. O custo, qualidade, as vezes até a cor e as dimensões tem um impacto importante no projeto da manufatura.

As características do processo são ainda mais importantes quando manufatura aditiva é combinada com outros processos como a usinagem, deposição, fundição....

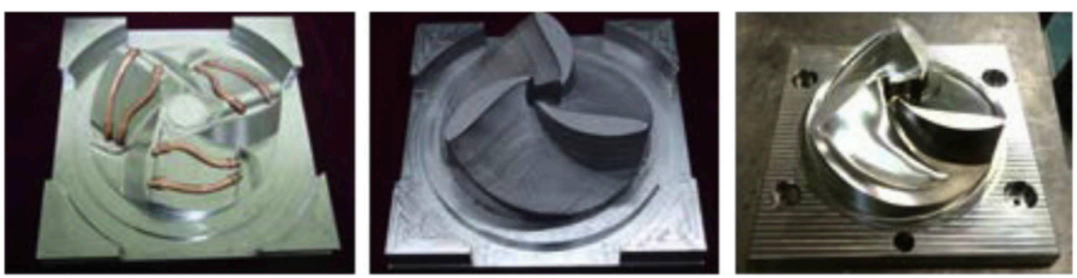
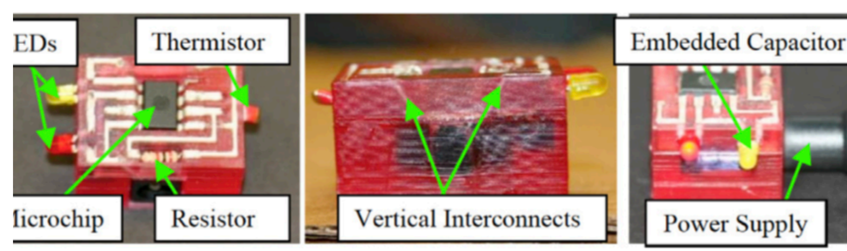


Fig. 5. Conformal cooling channels in an injection molding die. The cooling tubes were inserted into the substrate mold (left), the tubes were 'buried' and the die was completed using a laser-aided metal-based AM process (center), and the final tool was post-machined (right).
Adapted from [59].



. **6.** Timer circuit with embedded electronic components produced using a hybrid reolithography/direct print (SL/DP) machine [193].

Normas

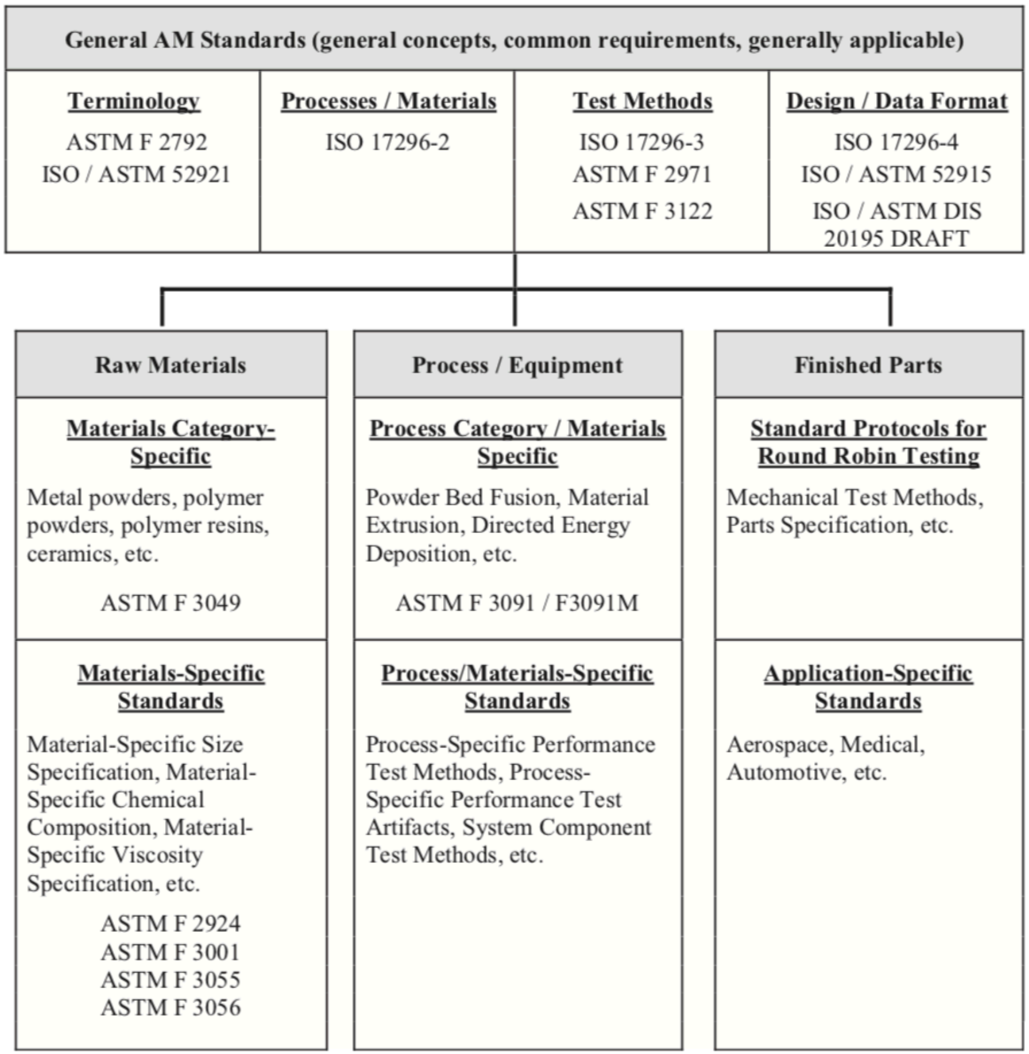


Fig. 7. ASTM and ISO standards for AM.
Updated and modified from [158].

Em 2013, ISO e ASTM definiram como objetivo comum definir normas para a manufatura aditiva.

Design for Manufacturing and Assembly

DfMA é a prática de projetar e otimizar um produto junto com seu sistema de produção para **reduzir o tempo e o custo de desenvolvimento** e aumentar o desempenho, a qualidade e a lucratividade. Isso é feito considerando simultaneamente os objetivos do projeto e
restrições de fabricação como “necessidades do usuário e do mercado, materiais, processos, métodos de montagem e desmontagem", requisitos de manutenção, etc.

O DfMA pode ser visualizado em três níveis de abstração.

No primeiro nível, o DfMA oferece ferramentas, técnicas e diretrizes concretas para **adaptar um projeto a um determinado conjunto de restrições posteriores**. Geralmente, são específicos do processo (por exemplo, Projeto para Moldagem por Injeção), específicos do recurso (por exemplo, como tamanho da peça, peso e simetria afetam o tempo de inserção / montagem) ou específicos da atividade (por exemplo, como calcular o tempo mínimo de montagem teórico).

No próximo nível de abstração, o DfMA visa entender e quantificar o efeito do processo de design na fabricação (e vice-versa). Isso é necessário para **melhorar o desempenho do sistema de fabricação**, as qualidades de execução do produto (custo, funcionalidade, satisfação do cliente, etc.), as qualidades de evolução (vida útil) do produto (custos de segurança, confiabilidade, serviço e reparo) , etc.) e o potencial de longo prazo do business case associado (por exemplo, a capacidade de responder a picos inesperados na demanda de produtos) [20].

No nível mais alto, o DfMA explora a relação entre design e fabricação e seu impacto no designer, no processo de design e na prática de design. Nesse contexto, ele aborda tópicos como **seleção de materiais e processos, engenharia simultânea e como melhorar o CAD** para dar suporte ao DfMA

As características únicas dos processos AM permitem e exigem abordagens diferentes para o processo e a prática do projeto.

- Isso inclui novas abordagens para explorar espaços de design grandes e complexos;
- incorporar material, mesoestruturas e considerações de projeto em várias escalas;
- e superar as " barreiras cognitivas " impostas pela experiência passada e pelas técnicas de fabricação convencionais.

Design for Manufacturing and Assembly

A liberdade de design associada à Manufatura Aditiva está em:

- o nível da peça com complexidade em escala macro,
- o nível do material com complexidade em escala micro
- e o nível do produto com complexidade em escala múltipla.

Graus de liberdade do Design na escala de complexidade macro:

1. Material
2. Cores
3. Liberdade de geometrias

Fig. 9. Jewelry produced with AM: award winning Tiger Ring from OG-Art – pattern printed in wax on a Solidscape machine (via [34]) (left); Kinetic Ring from Vulcan Jewelry (available for purchase) (center, courtesy of Vulcan Jewelery); custom R2D2 inspired ring from Uptown Diamond and Jewelry – pattern printed in wax on a 3D Systems ProJet machine [4] (right).

Fig. 10. Home furnishings produced with AM: the Monarch Stool from Future Factories (left, via [90]); Quin.Mgx Pendant Light from Bathsheba Grossman printed in polyamide using SLS (available for purchase) (center, courtesy of Bathsheba Sculpture LLC); and decorative bowl by Carl Bass printed in stainless steel and bronze on an ExOne metal binder jet printer (available for download) (right, [114]).

Funcionalidade e desempenho pela criação de estruturas internas complexas .

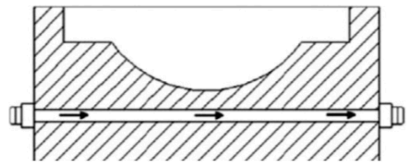


Fig. 13. Schematic of conventional cooling channel (left) and conformal cooling channel (right).
Adapted from [17].

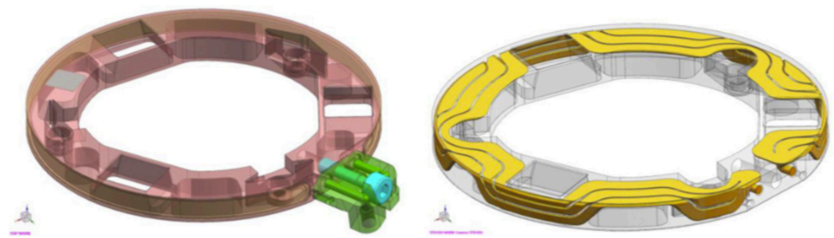


Fig. 14. Thermal conditioning ring with milled cooling channels enclosed by a welded cover (left) and with additively manufactured conformal cooling channels (right). Courtesy of ASML.

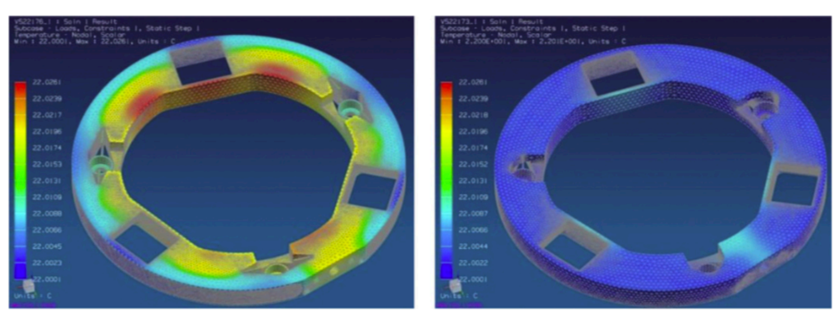


Fig. 15. Temperature plots from finite element models of the milled conditioning ring (left) and the additively manufactured conditioning ring (right). Shown with the same temperature scale. Courtesy of ASML.

Obtenção de macro-estruturas para a redução de massa e otimização do uso de energia (indústria automotiva, por exemplo) sem perda de vida do produto.

Fig. 16. Brackets before and after topology optimization: Airbus A320 nacelle hinge brackets as-designed for cast steel and optimized for titanium (left) and Airbus A380 brackets as designed and optimized for stainless steel (right) [105]. The optimized brackets were produced by direct metal laser sintering (DMLS).

Produção econômica de produtos sob medida e personalizados em massa

O fluxo de trabalho digital direto da MA e a geometria de forma livre podem ser combinados para fabricar objetos com qualquer grau de personalização.

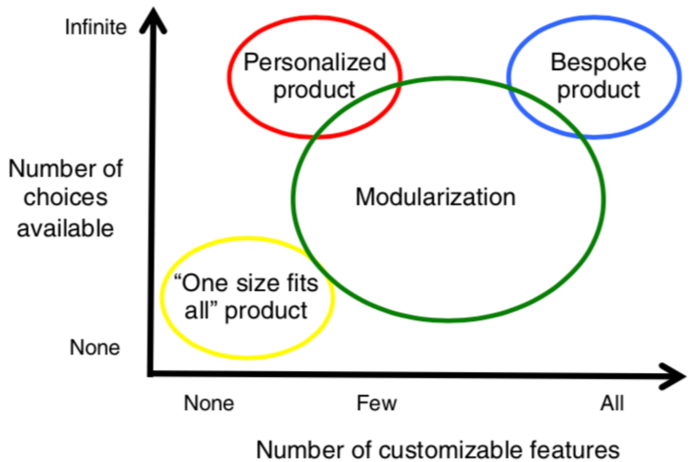


Fig. 17. Types of customization. Redrawn from [59].

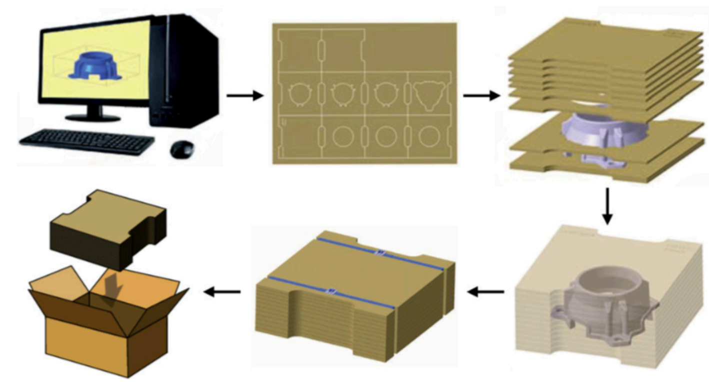


Fig. 21. Schematic of the Pack & Strat® process. Adapted from [34].

Fig. 18. Titanium implants for the skull (left, [103]) and pelvis (right, [107]) produced using an EOSINT M 280.

Fig. 19. Customized laser sintered foot orthoses from Materialise's A-Footprint project (left) and customized selective laser sintered wrist splint produced by Fraunhofer IPA. Images via [251].

Graus de liberdade em relação à microestrutura do material – micro escala

Comibar micro e meso estruturas para obter nossas propriedades formas e funcionalidade.

"Customização Metalúrgica" - composição química e microestrutura

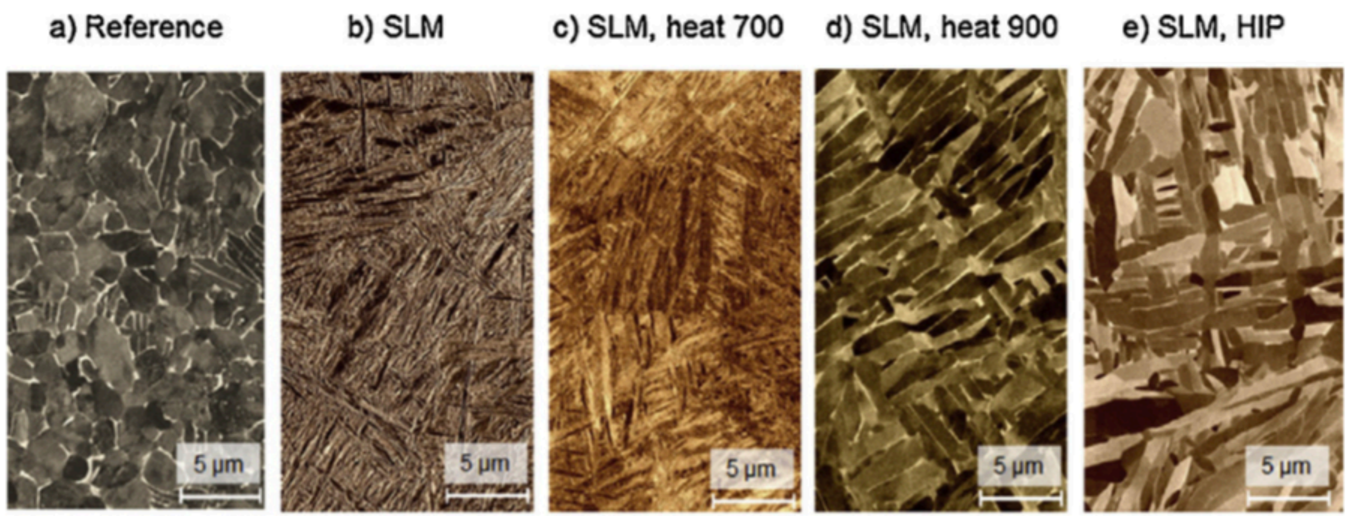


Fig. 23. SEM micrographs of etched surfaces showing the different grain structures of as-wrought (a) and SLM TiAl6V4 (b) with post heat treatment at 700 °C (c), 900 °C (d), or hot isostatic pressing (e).
Adapted from [164].

Customização das superfícies, texturas e porosidade para aumentar a funcionalidade.

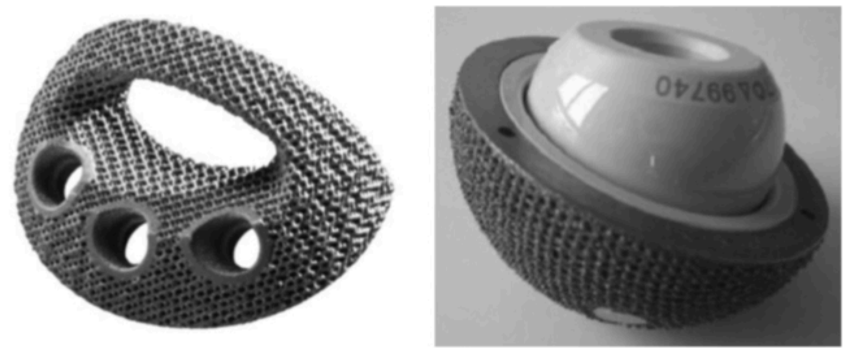


Fig. 24. Porous acetabular augment for hip revision arthroplasty (left, courtesy of Aesculap AG) and porous acetabular cup produced by EBM (right, [78]).

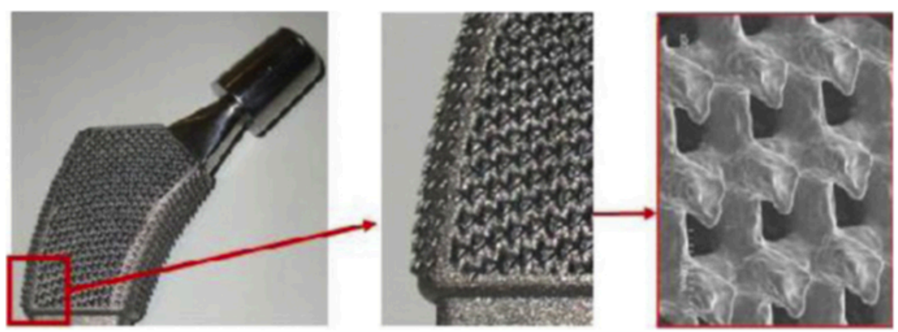


Fig. 25. OsteoAnchor™ implant with micro scale features to improve primary fixation produced by DMLS [141].

Reticulados, treliças, materiais celulares com propriedades customizadas e biofuncionalidade.

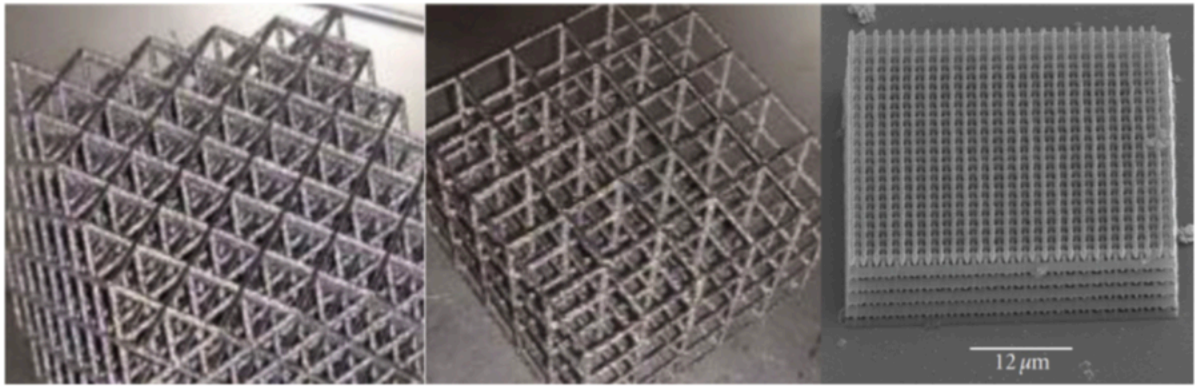


Fig. 26. AM lattices: octet truss lattice (left, [31]) and square lattice (center, [31]) produced using SLM, and photonic crystal with a micro woodpile structure made using two-photon polymerization (right, [247]).

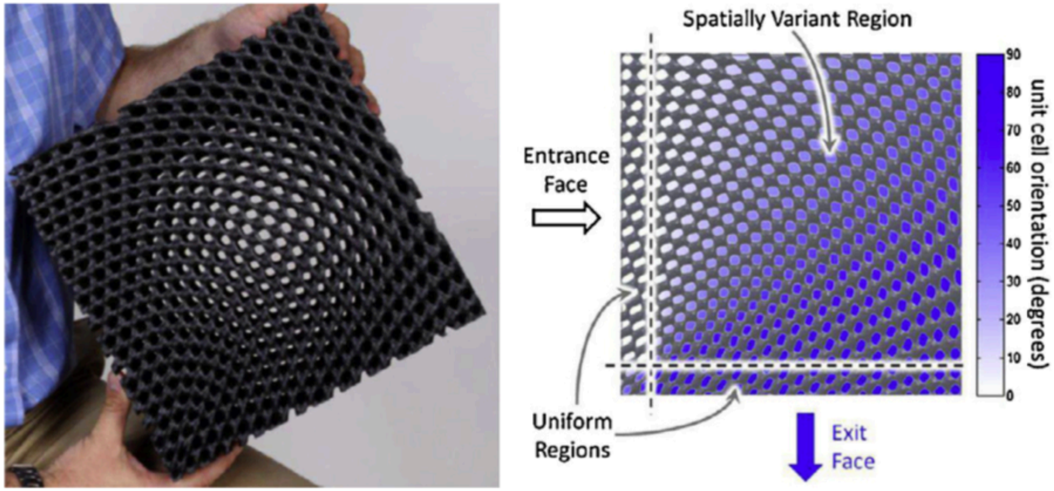


Fig. 30. Spatially variant self-collimating lattice produced using FDM (left) and a plot of the unit cell orientation over the part (right) [279].

Produtos Multimateriais

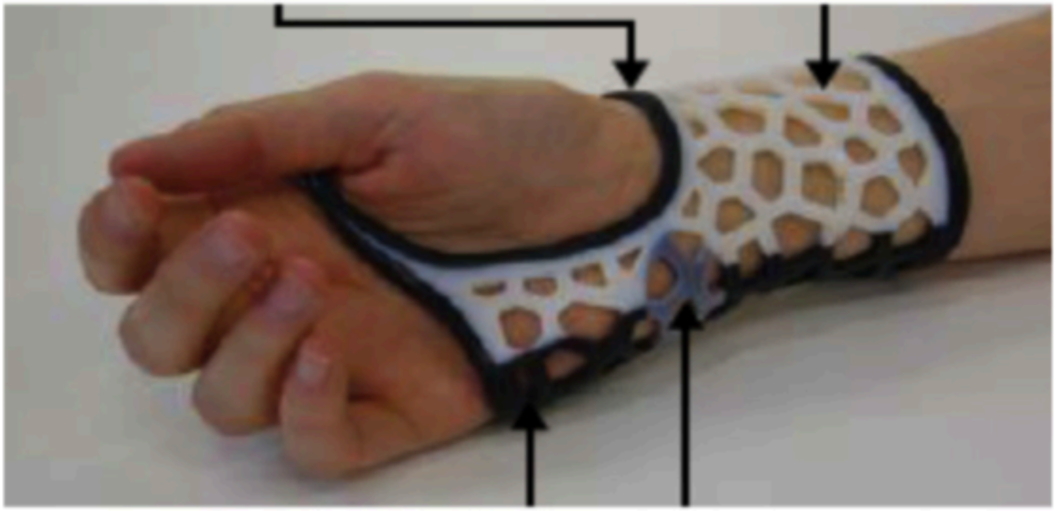
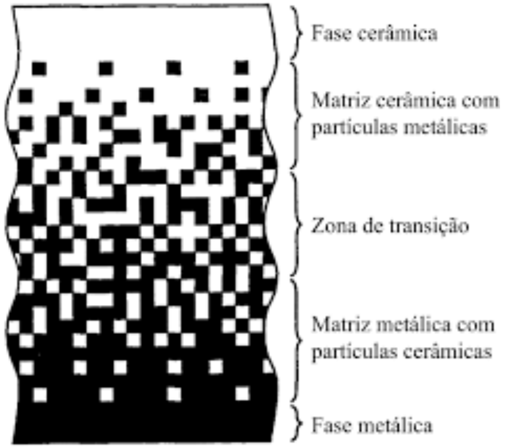


Fig. 31. Customized splint with multiple materials fabricated in a single build using an Objet Connex [252].

Materiais com gradação funcional

Fig. 32. Functionally graded flywheel (outer radius 0.2 m) composed of 320 stainless steel and copper coated nickel produced using the LENS process [233].



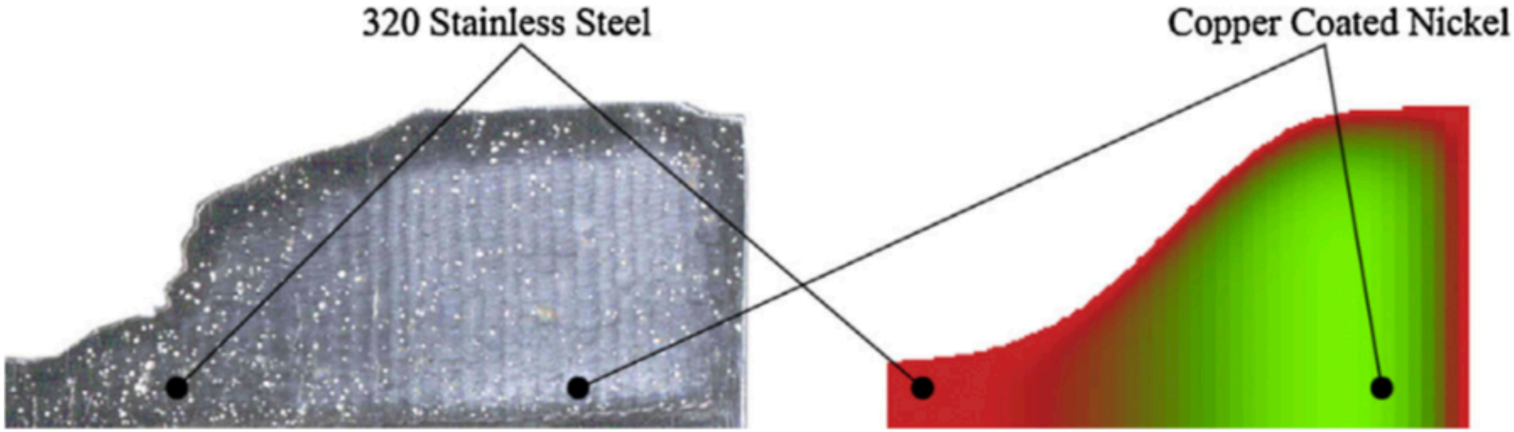
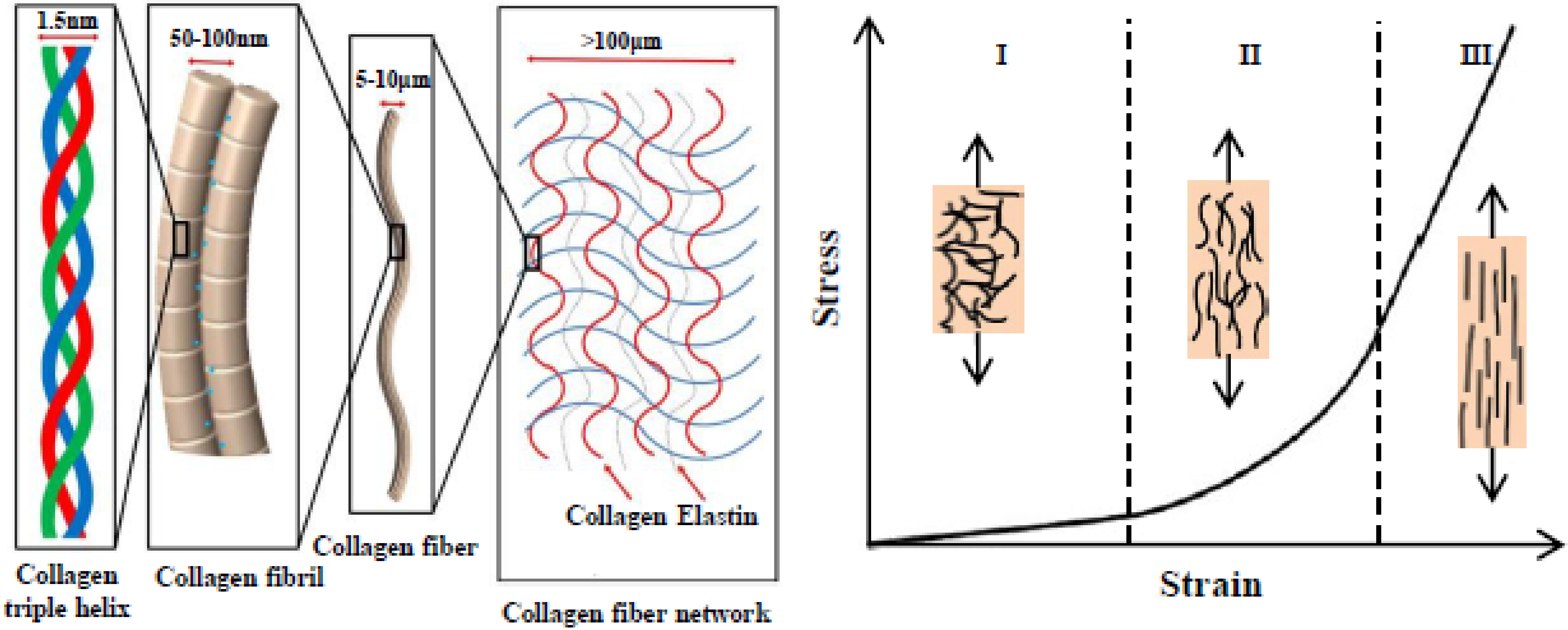


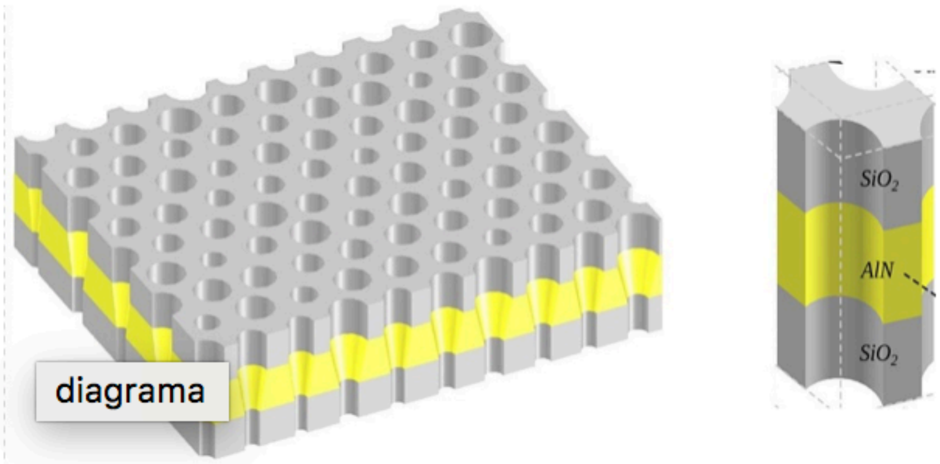
Fig. 33. Cross section of a functionally graded flywheel as designed (right) and as produced (left). The white spots are cavities that resulted from insufficient melting of the powder mix [233].


1.5nm
50-100nm
5-10μm
>100μm
Collagen Elastin
Collagen triple helix
Collagen fibril
Collagen fiber
Collagen fiber network
I
II
III
Stress
Strain

Metamateriais são materiais artificiais modificados de tal modo que adquiram propriedades desejadas que não existem de forma natural

Featured paper: Designing structures to manipulate light.

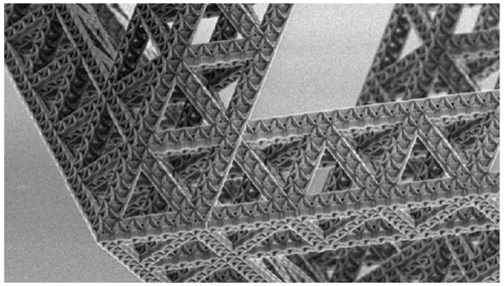
https://www.sbpmat.org.br/en/tag/metamateriais/



On the left, a diagram of a photonic crystal structure with some of the manufacturing defects studied. On the right, a diagram of the unit cell of the ideal photonic crystal designed by the scientists.

https://www.inovacaotecnologica.com.br/noticias/meta.php?meta=metamateriais

Metamateriais são materiais artificiais modificados de tal modo que adquiram propriedades desejadas que não existem de forma natural



Arranjo dos nanotubos cerâmicos.
Fonte

Um outro exemplo deles é estudado pela Prof. Katia Bertoldi da Harvard University, que possui um coeficiente de poisson negativo, ou seja, quando o material ele é comprimido na direção y, por exemplo, ele será comprimido em todas as outras direções. E quando ele é esticado, também será expandido em todas as direções. O coeficiente afeta também na fadiga de um metal, por isso uma pesquisa é feita com parceria com a Rolls Royce para obter um design do produto que resistirá a mais ciclos de compressão antes de fraturar.

http://engenheirodemateriais.com.br/2015/08/08/os-materiais-que-vao-contra-as-leis-da-natureza/

Restrições e considerações de qualidade no Design for Manufatura Aditiva

Embora a Manufatura Aditiva pareça ter um potencial ilimitado, ela não possui recursos ilimitados.

Os designers devem levar em consideração muitos tipos de restrições, incluindo aquelas associadas ao CAD e a digitalização de suas ideias;

A discretização digital e física das peças a serem produzidas;

As características dos processos de MA e os recursos atuais das máquinas de MA;

Restrições e considerações de qualidade no Design for Manufatura Aditiva

O impacto do processamento da MA nas propriedades do material e os requisitos para o processamento de materiais usando várias técnicas de MA;

Novos desafios e requisitos associados à metrologia e controle de qualidade;

Requisitos e considerações ao longo da vida, como manutenção, reparo e reciclagem;

Fatores externos, incluindo o ambiente regulatório. Embora muitas dessas restrições também se apliquem a outros tipos de tecnologias de fabricação, a natureza ascendente da MA significa que elas podem ter implicações muito diferentes para os designers

Restrições associadas ao CAD e digitalização

Restrições associadas à discretização e direcionalidade - O impacto da discretização e orientação na rugosidade da superfície e nas propriedades do material

A necessidade de estruturas de suporte durante a produção

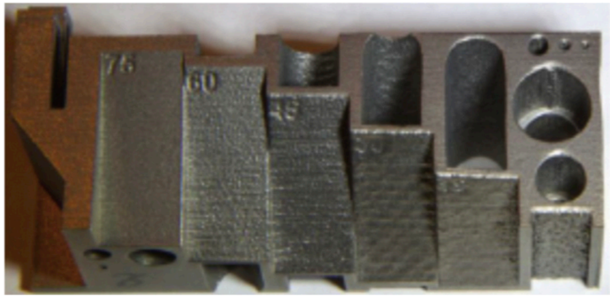


Fig. 38. Benchmark showing the surface roughness resulting for SLM parts with different build angles. Courtesy of ASML.

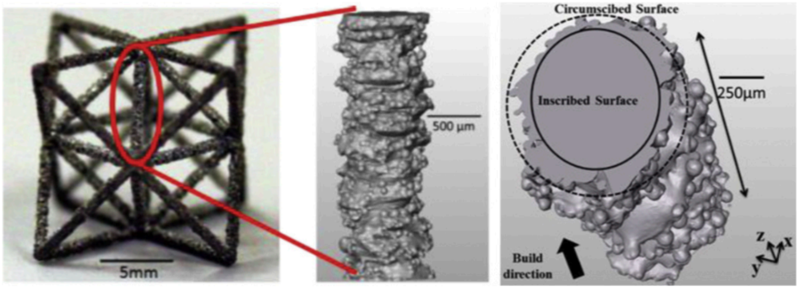


Fig. 39. EBM octet-truss unit cell (left), 3D reconstruction of a 1 mm strut from X-ray tomography (center), and an isometric view of the strut showing the diameter variation by the inscribed and circumscribed diameters (right). Adapted from [314]. Note that the strut exhibits surface roughness at length scales associated with the layering and with the powder.

Reduzindo as restrições do processo para criar novas oportunidades

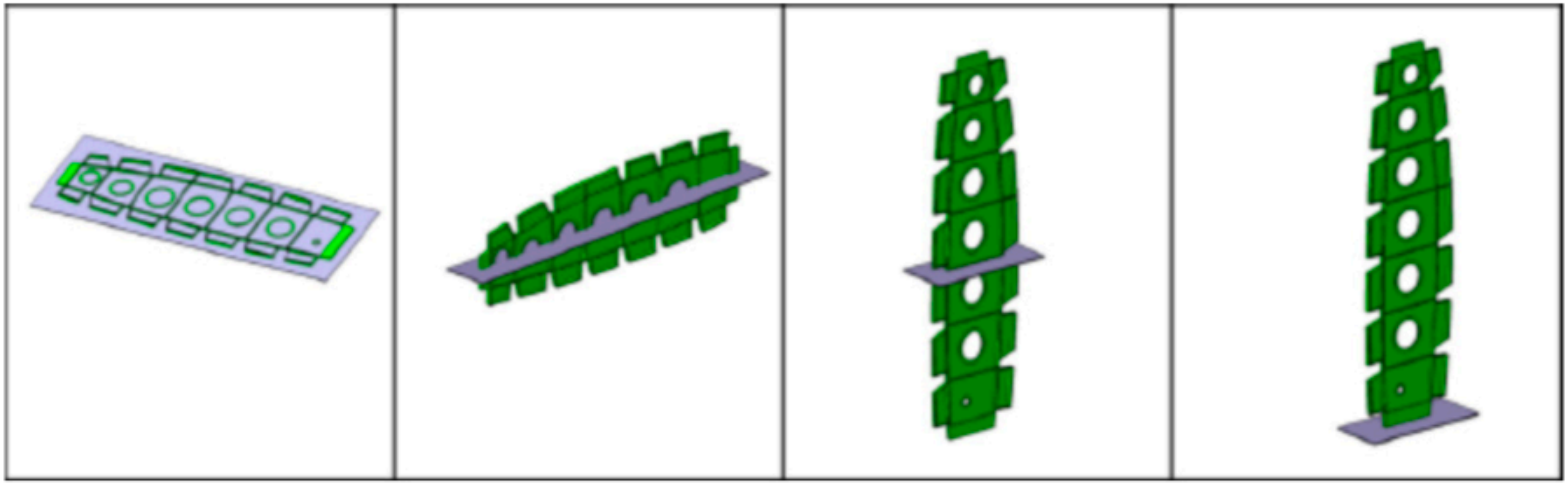


Fig. 44. Examples of unidirectional (far right) and bi-directional build orientations along the three planes of symmetry for a wing rib. Based on [116]. Images courtesy of the Welding Engineering and Laser Processing Centre at Cranfield University.

As características específicas do processo, as restrições específicas da máquina, a escolha do (s) material (is) e, em alguns casos, a estratégia de suporte impõem limitações às peças que podem ser construídas e definem as qualidades e características das peças:

- Elas determinam a deformação, contração, tolerâncias e precisão da peça;
- A estabilidade dimensional da peça; a rugosidade da superfície da peça em x, ye z;
- O tamanho mínimo do recurso em x, y e z;
- O espaçamento mínimo entre os recursos; a proporção máxima de aspecto de um recurso; e os recursos e formas não suportadas e suportadas que podem ser produzidas.

Table 2
Relative contribution of AM machine procurement cost to total product cost for FDM, SL, SLS [148], EBM, and DMLS [38]. A factor of 1.3 was used to convert £ to € for the EBM and DMLS parts.

	Polymers (2003)			Metal (2016)	
	FDM	SL	LS	EBM	DMLS
Annual AM machine costs (k€)	23	219	73	57	59
AM machine cost per product/build (€)	2.64	3.92	0.52	513	1964
Total cost per product/build (€)	4.47	5.25	2.20	1246	4183
Relative AM machine cost per product/build (%)	59	75	24	41	47

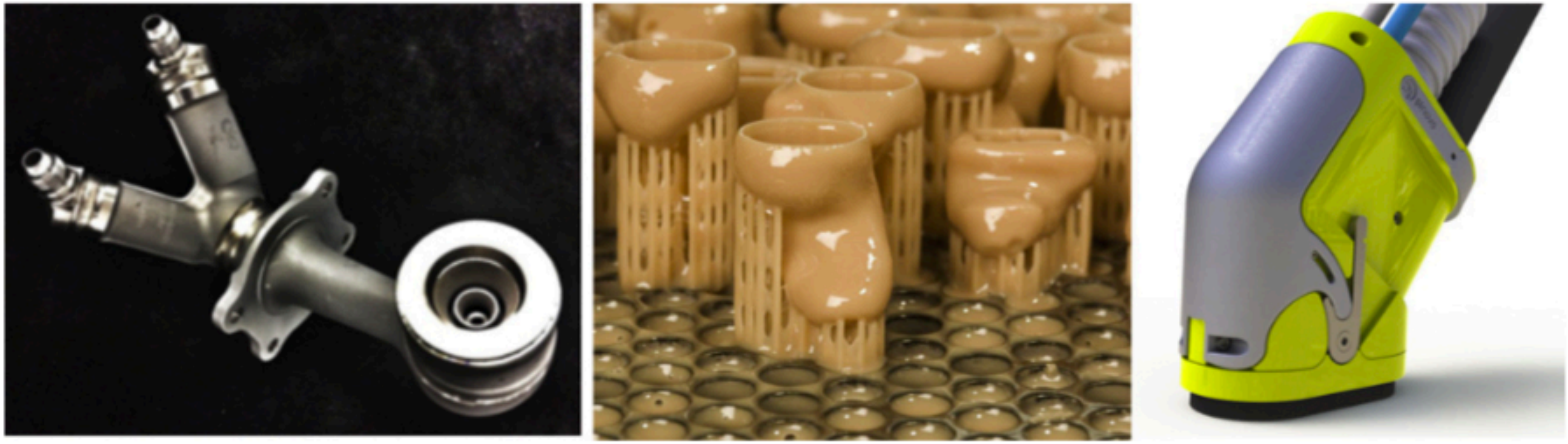


Fig. 53. Commercially successful AM products: GE Aviation fuel nozzle for the LEAP engine (left, [124]); hearing aids produced by vat polymerization (center, [117]); and the casing of the handheld Piblaster from Pinovo as produced by Materialise (right, [211]).

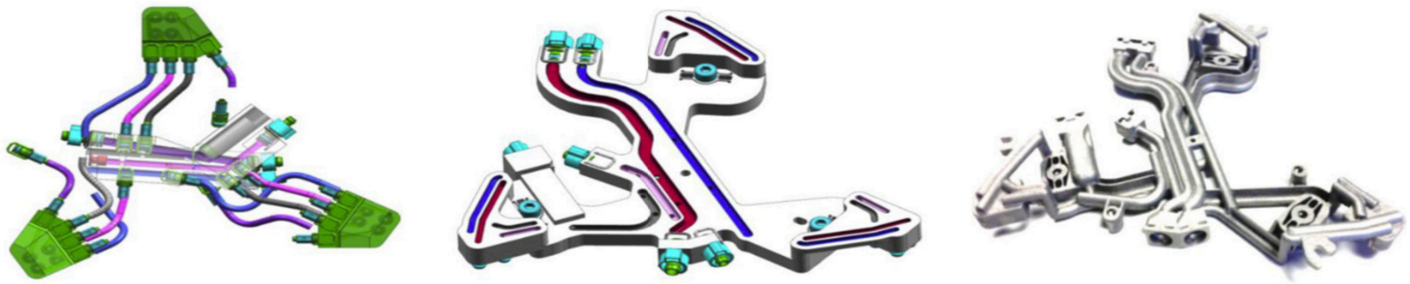


Fig. 55. Three designs of a manifold from the semiconductor industry: conventional design made of PEEK with hoses (110 g) (left), monolithic design milled in TiGr5 (200 g) (center), and optimized design printed in TiGr5 using SLM (100 g) (right). Courtesy of ASML.

Table 3
Cost breakdown of the three manifold designs shown in Fig. 55 as a percentage of the total cost of the conventional design. Courtesy of ASML.

Concept	Material & standard parts	AM cost	Machining cost	Welding/assembly cost	Treatments/cleaning/quality	Overhead/risk/profit	Total cost
PEEK & hoses	15%		33%	21%	8%	21%	100%
TiGr5 milled	1%		59%	54%	4%	38%	156%
TiGr5 SLM	4%	113%	28%		3%	35%	185%

Fig. 58. Examples of crowdsourced redesigned aerospace engine brackets [62].

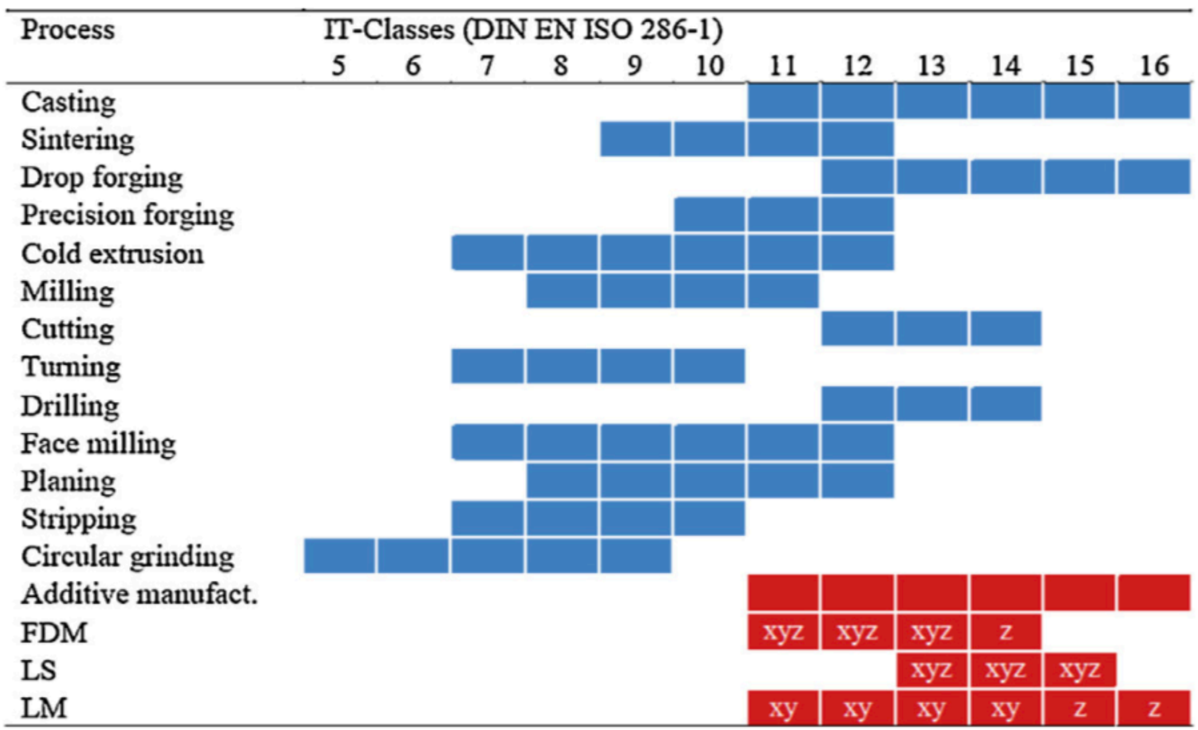


Fig. 59. Achievable tolerances of select traditional and AM processes [189].

Atividade

Ver todos os videos do youtube indicados. Liste o que gostou e o que não gostou em cada um deles!

FIM