A design framework for additive manufacturing

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Abstract

Additive manufacturing (AM) is one of the fastest growing and most promising manufacturing technologies, offering significant advantages over conventional manufacturing processes. That is, the geometrical flexibility that leads to increased design freedom is not infinite as the numerous AM processes impose manufacturing limitations. Abiding by these manufacturability rules implies a backpropagation of AM knowledge to all design phases for a successful build. A catholic AM-driven design framework is needed to ensure full exploitation of the AM design capabilities. The current framework is based on the definition of the CAD aspects and the AM process parameters. Their dependence, affection to the resulted part, and weight on the total process determine the outcome. The AM-driven design framework prevents manufacturing issues of certain geometries, that can be effortlessly created by conventional manufacturing, and additionally exploits the full design-freedom potentials AM has to offer with a linear design flow reducing design iterations and ultimately achieving first time right AM design process.

Keywords Additive manufacturing · Design for AM · AM design framework · Manufacturability · Design aspects · Design considerations

1 Introduction

One of the most promising value propositions of the additive manufacturing technologies is the zero-cost geometry flexibility, assuming part manufacturability. Benefits such as design freedom, integrated design, production flexibility with no need of product-specific tools, and lead time reduction for short series production are assets that AM can offer to the industrial sector [1, 2]. Yet the wide spectrum of AM technologies comes along with numerous manufacturing limitations [3].

These limitations emerge to the latest phases of a part design, which causes multiple design iterations until complete obedience to the AM rules for manufacturability. P. Pradel et al. (2018) mapped the AM design data and knowledge for all design phases [4]. The objective of this AM-driven design framework is to categorize, analyze, and integrate the current data from the last two design phases and backpropagate to the

detailed design. The scope of this work is to reduce design iterations to a first time right approach and exploit the advantageous nature of AM design.

At the early stages of a part's design, the design engineer should account the design aspects and design considerations (see dissemination of these definitions below) of the AM processes, acting based on the proposed design framework to meet the part's specifications and achieve optimum manufacturability. Non-compliance to AM rules is causing a bottleneck to the AM process. Supplementary features are added, or others are suppressed so that the designed part can be successfully manufactured.

A mapping of the design aspects will be presented and finally, an AM-driven design framework with a computational mindset for manufacturability will be proposed. This design gap has been identified from existing literature [5].

2 Establishing the design aspects and considerations

Establishing the terms design aspect and design consideration is crucial to the understanding of the AM-driven design framework (Table 1). It will also contribute to the further development of the DfAM framework (Fig. 1).

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Table 1 Nomenclature

Acronym	Definition	Meaning
AM	Additive manufacturing	Unconventional manufacturing technology
DfAM	Design for additive manufacturing	A generic term used to describe rules and parameters for a part design to be produced with an AM process
	Design aspect	Part's feature or process's parameter
	Design consideration	Any resulted outcome

Fig. 1 Defining Aspects and Considerations for AM Design

Design aspect is defined as any particular feature which can be quantified at the design phase. That includes geometric features of the part's shape (overhangs, bores, channels, etc.) and part's programming parameters (layer thickness, orientation, etc.).

Design consideration is the result on the manufactured part. These considerations can be very specific properties of the process and quantified with certain KPIs. That is, a design consideration can be a mere generic goal of the AM process

such as achieving a first time right manufactured part or a specific one like part surface roughness.

Following the establishment of these terms, comes the categorization of the current DfAM academic publications and tacit industrial knowledge in datasheets with all their parameters quantified. The next step is to develop a design framework of the bellow, dense in information blocks to extract manufacturability knowledge and thus morph the optimum part design. With conventional manufacturing processes, these aspects are mostly a concern for the production engineer rather than for the industrial designer; yet, the significance of these aspects is high for the outcome in AM technologies [4].

2.1 Design aspects

The design aspects of the AM process, presented below, are organized in two main categories: part's geometric features and process parameters.

2.1.1 Geometric features

Similar to conventional manufacturing, there are restrictions regarding the geometries that can be built. The layer-by-layer

Fig. 2 Build vector depicted on a PBF AM machine (adapted from [7])

Fig. 3 Overhanging geometries created with PBF AM technologies [8]

Fig. 4 Overhanging geometries categories

principle followed by AM machines has its limitations since each layer must be built directly above the previous one [6]. That is, not every geometry is possible as each geometrical feature must obey to a certain geometrical continuity. Once this geometric continuity is overlooked in the design, the resulting part will suffer in its integrity (e.g., deformation, porous mass, reduced density). The design aspects that determine the quality of the outcome are presented in the following chapters.

Overhanging geometries Manufacturing overhanging geometries is a trite, yet challenging feature for the majority of the

AM processes. A generic definition of an overhanging geometry is any geometry whose orientation is not parallel to the build vector (Fig. 2). The ability of the AM machine to manufacture a layer of material displaced to the previous, defines its ability to create overhanging geometries. The magnitude of this layer's parallel shift sets the limit for the maximum overhang length and the maximum slope angle.

However, overhanging geometries can be successfully manufactured, with the addition of support structures; yet, they might be proven of poor layer adhesion or post-processing demanding (Fig. 3) [9, 10]. A support structure guarantees a successful build yet compromises the surface quality of the part, reason for being the support structures and part are overlapped [10]. It also decreases the efficiency of the AM process-build time, material, post-processing equipment, and process cost and contradicts its advantageous

⁰ Manufacturability for conventional process is a duality. A feature can or cannot be manufactured. Yet for AM process, there are intermediate states where a feature can be manufactured with the aid of support structures

Table 2 Overhang limit per AM Technology

Overhangs		Vat Polymerization			Extrusion	Material jetting			Binder jetting	Powder bed fusion				Direct energy deposition		Sheet
	(mm)	SLA	DLP	CDLP	FDM	MJ	NPJ	DOD		MJF	SLS	SLM	EBM	LENS	EBAM	LOM
	No Need			N/A		[14]	[14]	[14]		N/A			N/A		N/A	[15]
	50				[14]											
	10				[16]				[14]		[14]					
	7								[17]							
	5															
	0.5											[18] [14]				
	Supports	[14]	[14]											[15]		

net-shape manufacturing nature. Therefore, in order to increase AM manufacturability,¹ it is desirable that the part only has self-supported geometrical features.

The most important overhanging geometries that need to abide AM limits are presented (Fig. 4).

Overhangs Overhangs are one-sided abrupt geometry changes. The horizontal distance an AM machine can build without supports is limited and if exceeded, the whole build could fail. The limit of an overhang length is affected by numerous factors and the nature of the AM technology [11–13]. As discussed above, the AM process, the material used, and even the actual machine are variables to the equation that defines the maximum overhang length.

When part specifications call for a greater overhang, the decision to be made is whether to alter the part's geometry or maintain it and add supporting structures. Indicative overhanging lengths are presented in Table 2. The simplest way to resolve this is to replace horizontal overhangs with angled ones. In case that an angled overhang adaption is not feasible, due to the specifications and the geometry of the part, a support structure needs to be introduced to support the overhanging feature. The design decision-making process regarding horizontal overhangs is summarized in Fig. 5.

Angled overhangs Another category of the overhanging geometries is the angled overhang. In correlation with the length

Fig. 5 Overhang's decision-making schematic

Table 3 Angled overhangs for AM technologies

Angled overhangs		Vat Polymerization			Extrusion	Material jetting			Binder jetting	Powder bed fusion				Direct energy deposition		Sheet
	(degrees)	SLA	DLP	CDLP	FDM	MJ	NPJ	DOD		MJF	SLS	SLM	EBM	LENS	EBAM	LOM
	No Need			N/A		[14]	[14]	[14]	[19]	N/A			N/A		N/A	[15]
	60°											[20]				
	55°															
	45°				[14]											
	Supports	[14]	[14]											[15]		

of the overhangs, the overhanging angle of angled overhangs is also a geometrical limiting factor to most AM technologies. Some AM technologies can produce angled overhangs of certain gradient where others cannot (Table 3). These numbers can diverge highly in certain parts whose surface quality is acceptable to be poor and if the process parameters have been set up correctly [21].

For extrusion AM technologies, extreme angled overhangs cannot be created as material cannot be deposited in midair [12]. For powder bed fusion AM technologies, the powder surrounding the part acts as a support and thus, steeper angled overhangs can be realized. That is, there is a drawback regarding surface roughness as the surrounding powder is sintered unevenly on the downward facing areas of the part.

Bridging Similar to overhangs, a bridge is a horizontal geometry between two or more non-horizontal features (Fig. 6). A bridge is defined as any surface in the part geometry that is facing down between two or more features. Related to the previous restrictions, the designer must take into consideration the maximum length that the machine can bridge. If this length exceeded, the part will not be successfully manufactured (Table 4).

Bores and channels Manufacturing parts with internal geometries is a major benefit and desirable feature for AM technologies. Manufacturing internal bores that are impossible with traditional manufacturing methods is feasible with AM, without additional cost [23]. That enables profound geometrical

Fig. 6 (a) Overhanging angles in a test part manufactured with SLM technology, modified from [18]. (b) Overhanging angle-surface roughness, adapted from [22]

Table 4 Bridging length for AM technologies

Bridging		Vat Polymerization			Extrusion	Material jetting			Binder jetting	Powder bed fusion				Direct energy deposition		Sheet
	(mm)	SLA	DLP	CDLP	FDM	MJ	NPJ	DOD		MJF	SLS	SLM	EBM	LENS	EBAM	LOM
	No need			N/A		[14]	[14]	[14]		N/A			N/A	*	N/A	N/A
	2											[14]				
	10				[14]											
	20								[14]							
	50										[14]					
	80															
	Needs supports	[14]	[14]													

*DED technologies can bridge long distances if the head is operated with a robotic arm (counter to operation on a CNC table), as with the arms orientation freedom bridging a horizontal feature can be manufactured as a vertical one.

flexibility allowing the creation of parts with internal concave channels—achieving great heat convection capabilities or optimum fluid flow [24, 25]—or structural reinforcement—lattice structures [26, 27]. The major AM advantage of conformal cooling channels that follow complex paths through the volume of the part increases the heat transfer capacity which in mold manufacturing processes provides efficient cooling to mold cavities and reduces cooling time [24].

To properly implement these advantageous features in the AM part design, compliance with the AM design aspects limits is mandatory. Bores and channels are subject of the

overhanging geometries, acting as partially overhanging cavities (Fig. 7). That is, their limits are sometimes different as seen in Table 5.

Wall thickness There is a minimum wall thickness that is feasible to be manufactured for each AM process. This is due to the building threshold determined by the fundamental unit of the AM machine—diameter of laser beam, flow focal point, or nozzle—and the fact that the machine needs to make multiple passes to build a sufficient and solid feature. Indicative minimum wall thicknesses are shown in Table 6. Another

Fig. 7 Bores or channels are subjects overhanging geometry when perpendicularly manufactured

Table 5 Bores and channel's dimension limits for AM technologies

Bores and channels	Minimum diameter (mm)	Vat Polymerization			Extrusion	Material jetting			Binder jetting	Powder bed fusion				Direct energy deposition		Sheet
		SLA	DLP	CDLP	FDM	MJ	NPJ	DOD		MJF	SLS	SLM	EBM	LENS	EBAM	LOM
	0.4			N/A				N/A		N/A			N/A	N/A	N/A	N/A
	0.5															
	0.75															
	1.25															
	1.5															
	2.0															
	3.0															
	4.0															
	5.0															

Table 6 Minimum wall thickness for AM technologies

Min. wall thickness	(mm)	Vat Polymerization			Extrusion	Material jetting			Binder jetting	Powder bed fusion				Direct energy deposition		Sheet
		SLA	DLP	CDLP	FDM	MJ	NPJ	DOD		MJF	SLS	SLM	EBM	LENS	EBAM	LOM
	0.1						N/A	N/A					N/A	N/A	N/A	N/A
	0.2															
	0.25															
	0.3															
	0.4															
	0.5															
	0.6															
	0.7															
	1.0															
	1.6															
	2

Fig. 8 Different path line's width for path planning for a given part's cross-section

accountable parameter for thin walls is the height-to-thickness ratio. Oblong wall structures tend to collapse.²

An important path planning aspect when designing thin walls, close to the limits of the AM machine, is that some geometries cannot be precisely depicted as the slicing software which generates the G-code is not able to create the desired geometry (Fig. 8) [28, 29].

Below the lower limit of the allowed thickness, the wall feature cannot be formed, or when formed, will suffer from deformation [30]. An integer multiple of the fundamental tool path width must be used for the design. When the geometry's width that must be manufactured is not an integer multiple of the fundamental tool path width, the slicer software will have to compensate for that issue. Some of the most common ways to tackle this is to skip or overlap a certain line of the sliced surface. Another approach is to try and alter the tool path width. These solutions are, for the most part, insufficient as the integrity of the part is compromised or a generic parameter of the machine deviates from the optimum. This could cause a deviation of the dimensional accuracy and the mechanical properties.

A filling indicator is introduced to determine whether the path plan creates a sufficiently dense part.

Table 7 Smallest geometrical feature for AM technologies

Smallest feature	(mm)	Vat Polymerization			Extrusion	Material jetting			Binder jetting	Powder bed fusion				Direct energy deposition		Sheet
		SLA	DLP	CDLP		MJ	NPJ	DOD		MJF	SLS	SLM	EBM	LENS	EBAM	
	0.1							N/A				N/A	N/A	N/A	N/A	
	0.2															
	0.25															
	0.3															
	0.5															
	0.6															
	0.7															
	1.6															
	2															

Table 8 Fundamental build unit per AM technology

Fundamental unit	Vat polymerization			Extrusion		Material jetting		Binder jetting		Powder bed fusion			Direct energy deposition			Sheet
	SLA	DLP	CDLP	FDM	MJ	NPJ	DOD			MJF	SLS	SLM	EBM	LENS	EBAM	LOM
	Laser spot130–150 μm	Projector voxels 1024 × 780	Projector light source	Nozzle diameter 0.15–1.0 mm	Line-wise 1D scanning	Heads with multiple nozzles	Single moving point 5000 × 5000 dpi	Print head depositing 80 μm binder droplets	Jet nozzle	Laser spot and powder particle	Laser spot and powder particle	Laser beam size 0.2–1.0 mm	Beam spot size 0.2–1.0 mm	Nozzle beam diameter 0.3–0.5 mm	Wire diameter 0.9–4 mm	Inkjet, polymer deposi- oner

$$FI = \frac{D_f \sum L_i}{A_{cs}} \quad (1)$$

where D_f is the diameter of the fundamental build unit, L_i the length of each path, and A_{cs} is the surface area of the cross section.

There are physical constraints when building thin walls as they are difficult to form and can be easily distorted [31, 32]. The successful manufacturing of a thin wall is not always a hardware concern. The slicing software determines the G-code for the AM machine's fundamental building unit to follow, which can bottleneck the build [33]. A thin feature can be overlooked by the slicing software, although the machine can manufacture that feature in certain optimum scenarios [29].

Smallest features Apart from the minimum wall thickness, which is considered a 1D thin feature, there are more small features that challenge the ability of the AM machine when it comes down to manufacturability [34]. A 2D thin feature an AM machine can manufacture is usually referred to the diameter of the smallest possible pin [29]. It could also refer to the side of a rectangular or a complex-curved geometry. This aspect should be considered at the design phase, as it defines the detail that can be introduced to the part. The smallest features of AM technologies can be seen in Table 7.

2.1.2 Process parameters

Process parameters are selected at the slicing phase³ of the AM process. They are highly interconnected with the AM technology and the individual machine. The proper AM design considers the build orientation and the layer thickness. In Table 8, the fundamental AM machine units that build the part layer-by-layer are presented.

Layer thickness Layer thickness is a factor that affects both the quality of the print and the build time needed to complete the part. With smaller layer thickness, a more detailed part is produced, and the staircase effect is minimized. Additionally, with smaller layer thickness, potential voids and gaps are eliminated, as the CAD file is being sliced with more precision and the geometry accuracy is maintained. On the counterpart, with thicker layers, the printing time is reduced [35]. Regarding the staircase effect, another factor that is causing it is the slope angle. As the angle increases, the cosine is proportionally increasing the stair size [36]. Indicating layer thicknesses for AM technologies are presented in Table 9.

Table 9 Layer thickness for AM technologies

Layer thickness		Vat Polymerization			Extrusion	Material jetting			Binder jetting	Powder bed fusion				Direct energy deposition		Sheet
	(μm)	SLA	DLP	CDLP	FDM	MJ	NPJ	DOD		MJF	SLS	SLM	EBM	LENS	EBAM	LOM
1	1	MSLA [37]											N/A			
	3															
	6															
	8															
	16															
	20											[38]				
	25															
	32															
	50								[14]							
	70															
100	100										[14]					
	120															
	130													[38]		
	150															
	380															
	400															
	1000															

A proposed solution to this matter is adaptive slicing. The areas where detail is needed are sliced with thin layer height, whereas areas that their quality is not affected are sliced with thicker layer height to contribute to an effective build regarding time and energy consumption [39].

Build orientation The build orientation is one of the most crucial process parameters. The orientation of the part relative to the build vector of the fundamental build unit determines which geometrical features are overhanging geometries. Subsequently, the build orientation determines the volume of support structures needed to successfully manufacture the part [40, 11]. Moreover, it sets the axis on which the mechanical properties show anisotropic behavior.

2.2 Design considerations

As defined at the beginning, a design consideration is any resulted affection on the finished product. That includes mechanical properties of the part, KPIs of the AM process or even more abstract goals like first time right design and manufacture. Presented below are the most important design considerations.

2.2.1 Anisotropic mechanical properties

AM technologies produce parts with anisotropic mechanical properties. The anisotropic behavior is rooted to the AM nature and can be traced back to four different causes: lamellar nature, cylindrical extrusion shape (FFF technologies), short fibers within the raw material, and scaffold and lattice

Fig. 9 **a** The lamellar nature. **b** Cylindrical extrusion shape of the FDM process. **c** Short fiber alignment during the extrusion process of a composite. **d** Lattice structures [41]

structures within the volume of the part (Fig. 9) [41, 49]. Mitigating the anisotropy with heat treatment improves to some extent the mechanical properties. However, it is not feasible for components that cannot fit to a furnace, thus it needs to be pointed as a design consideration for AM.

Having said that, there are two approaches to design a part with a given load case. The first one is to orient the designed part in such a way that the loads are received in the direction which the AM technology has the greatest mechanical strength. The other, more sophisticated approach is to shape optimize the part with the mechanical strength anisotropy in mind [41, 43].

2.2.2 Accuracy (xy plane vs z axis)

Another important design consideration is to distinguish between the machine's accuracy on the xy plane and z axis. The accuracy of the machine that will produce the desired part is crucial for the designer at the designing phase. For pre-assembled builds or assemblies in general, the dimensional accuracy with which the machine can manufacture has to be considered for the build to be a success.

Table 10 Surface quality for AM technologies

	Ra	Vat polymerization			Extrusion	Material jetting			Binder jetting	Powder bed fusion				Direct energy deposition		Sheet
	(μm)	SLA	DLP	CDLP	FDM	MJ	NPJ	DOD		MJF	SLS	SLM	EBM	LENS	EBAM	LOM
Surface roughness	1.6															
	9													[38]		
	10													[44]		
	20															
	25													[38]		
	35													[44]		
	61														[38]	
	91															
	Rough															

Table 11 Base cross-section requirement per AM technology

Base cross-section	Vat polymerization				Extrusion		Material jetting		Binder jetting	Powder bed fusion			Direct energy deposition			Sheet		
	SLA	DLP	CDLP	FDM	MJ	NPJ	DOD	MJF		SLS	SLM	EBM	LENS	EBAM	LOM			
	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion	Adhesion and heat convection	Adhesion and heat convection	Adhesion and heat convection	Adhesion and heat convection	Heat convection	Adhesion and heat convection	Adhesion and heat convection	Adhesion			

2.2.3 Surface roughness

The roughness of the completed part is important, as it determines the post-processing steps in order to achieve the desired surface quality. The resulted surface roughness is not uniform throughout the entire surface of the printed part. This is caused by the geometry's slope angle and the unintentional sintering under angled overhangs [19]. Another reason for surface non-uniformity is the gaps resulted from insufficient filling of the path planning (see chapter "Wall thickness"). Chrysosolouris et.al. [43] have estimated the average surface roughness of SLA-produced parts as a function of the layer thickness and the angle of the inclined surface. Indicative surface roughness for AM technologies are presented in (Table 10).

2.2.4 Build time

The build time refers to the total time required for an AM machine to manufacture the part. The build time and build orientation of the part are highly related that is due to the fact that material deposition speeds on xy plane and z axis are not the same. The build unit (e.g., nozzle, laser) moves, thus builds the part, with greater speed on the xy axis, then the speed that the layers are adding up [45]. Changing the build orientation will affect the time needed for the AM machine to complete the part. Horizontally orientated parts will in general be printed faster than vertically orientated ones.

2.2.5 Part's cross-section area

The part's cross-section area (normal to build vector) is an important design consideration. The cross-section area affects the manufacturing process in two ways depending on the AM technology. The first one is related with the machine's build base. The second one is related with the stresses that are developed at the rest of the part's volume while its layers are manufactured. The second design consideration of the developed stresses on the part's cross-section area is related to its mechanical properties [41].

Machine's build plate and part's base consideration The first layers of the build are crucial for its completion. The part must be restrained at the build plate; thus, the adhesion between the part's base surface and the machine's plate is to be considered, apart from securing the part, through that common surface heat dissipation is achieved [46]. A thermal simulation for the heat concentration provides a picture for the design engineer, regarding residual stresses [47] The function that the part's base cross-section has per AM technology is presented in (Table 11).

Table 12 AM technologies that require small cross section area throughout the build

	Vat polymerization			Extrusion		Material jetting			Binder jetting		Powder bed fusion				Direct energy deposition			Sheet
	SLA	DLP	CDLP	FDM		MJ	NPJ	DOD			MJF	SLS	SLM	EBM	LENS	EBAM	LOM	
Develops residual stresses at cross-section	NO			Moderate							Yes	Yes	Significant	Yes	Yes	Yes	Yes	Yes

Part's cross-section and developed stresses consideration For the AM technologies that develop residual stresses (Table 12) (e.g., PBF, extrusion), it is desirable to maintain a small cross-section area to minimize residual stresses and thus deformation. This effect has a greater impact to more delicate and elongated structures such as CMF implants [48].

Lacking a coherent DfAM framework, the design process calls for numerous design iterations due to redesigning needs for adaptation to AM technologies [49]. To compensate that, a replacement of the infinite-freedom design mentality with the AM design aspects presented above, is needed. Methodically morphing the part's geometry, based on the design aspects, the design process becomes linear.

3 Approach: mapping design steps and defining the framework

The approach proposed in this paper uses the AM design aspects and considerations to define the part's geometry throughout the design phases. This methodology is aimed at

fully utilizing the AM process's advantageous nature and anticipate the manufacturability limits of the AM technology that will manufacture the part.

This is achieved with the backpropagation of the process and manufacturing information, which morphs the shape and characteristics of the design, resulting in a part that abides the DfAM rules from the first design iteration (Fig. 10). That is, the design process is made in a more linear fashion, eliminating time-consuming design iterations.

The previous approach for the AM-driven design framework makes the design process computation orientated.

4 Final considerations

When designing a part to be realized with an AM process, certain design aspects and considerations need to be taken into account. The existing design for manufacturing rules (DFM) for conventional processes contribute to the designer's psychological inertia, which drives the part design away from the AM advantageous nature. The layer-wise nature of all AM

Fig. 10 Conventional (orange) and proposed (blue) design process for AM

technologies comes along with specific geometrical limitations. Determining all design aspects that define a part's geometry and then quantifying their affection on the outcome is a necessity in order to optimize the AM process. The initial step of creating such a design framework for additive manufacturing technologies was to accurately define the design aspects, design considerations, and their dependence.

Working the part design as proposed above is of dual usefulness. First, it optimizes the conventional design process (geometry imposed by a human designer). The second contribution of this framework is related with the generative design shape optimizers. Although at their early stages, generative design seems to promise the future for part and assembly designs. The current quantification of design aspects and considerations and their true or false affection on AM manufacturability will secure the creation of optimized design that is at the same time AM ready to manufacture.

To drastically improve the AM production's efficiency, the complete design flow (conceptual, embodiment, and detail design) needs to be created with AM DfAM in mind. Only then, the AM technologies will be able to have their advantageous nature fully exploited.

5 Further work

This AM-driven design framework bridges the gap existing between the generic DfAM knowledge and the computational approach with the AM factors' parameterization. This unlocks the opportunity to paths where the weight of the factors and the method of the design process is implemented with data analytic methods. The AM designer's need for precognition can be replaced with intergraded ML algorithms that determine the optimum process parameters. Additionally, the morphing and manufacturability of the design can now be realized with shape algorithms. This AI approach to the AM design needs multiple data inputs from real-life manufacturing. The drift in manufacturing industry towards live process monitoring and communication between the different stages of production (IOT) serves the need for actual data to optimize the design algorithms based on the outcome result.

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