Design And Release Process For AM Parts

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Abstract. The paper presents the results of a survey that analyses the additive manufacturing (AM) industry's application of design and release processes based on a proposed "ideal" release process, which was developed with the knowledge and experience of the Product Lifecycle Management and additive manufacturing (AM) groups at the University of Applied Sciences. This process reflects modern computer-aided design (CAD) tools and their capability, e.g. to add the form and position tolerancing by 3D annotation (product manufacturing information, PMI). As the complexity of additive manufacturing emphasizes the importance of release processes, the requirements of "design for manufacturing" (DfM), especially "design for additive manufacturing" (DfAM), are also considered. Furthermore, the present way of designing AM parts (raw and final part) is reflected. A gap analysis is conducted on the survey results, whereby improvements to close the gap are discussed. This knowledge is used in a running scientific project with an industry partner to offer additive manufacturing services via an internet platform that calculates an immediate and quantity-dependent price offer.

Keywords: Release Process, Change Management, Additive Manufacturing (AM), Product Lifecycle Management, Design for Manufacturing

1 Introduction

The purpose of this paper's survey is to analyse the additive manufacturing industry's common design practises and degree of digitalisation as well as its specific opinions on and its utilisation of predefined design and release processes. This not only reflects the current state of the additive manufacturing industry, but also provides insight into the specific shortcommings of the companys' digitalisation and design processes, how those can be optimised, and why it is beneficial to do so.

1.1 Additive Manufacturing

Additive manufacturing (AM) is one of the newest manufacturing technologies [1] and is considered a primary shaping method ([2], chapter 39). As such, the design processes for additive manufacturing and casting deviate significantly from those of other manufacturing technologies, e.g. turning, where the designing engineer does not usually spend a considerable amount of time designing the raw part.

From a process point of view, there are effectively no additive manufactured or casted parts that do not require postprocessing, e.g. by milling. Hence, it is ideal to design the raw part before the final part. However, often the design process is executed backwards, and the final part is designed first and then used as the basis from which the raw part's design is derived.

This leads to less than ideal designs, which is only exacerbated by another challenge in the design process of additive manufacturing worth mentioning, despite not being investigated in this study, which is the industry's little established knowledge of "design for manufacturing" (DfM) [3], [4] or, more specifically, "design for additive manufacturing" (DfAM) [5]–[7]. For example, the orientation of an additive manufacturing part in the machine [8], [9] is critical for the supporting structure's complexity, the part's deformation and tension, and the overall effectiveness and efficiency of the manufacturing process. Therefore, a close cooperation between the designer and the additive manufacturing expert is required to achieve an optimal result. In that respect also, additive manufacturing is similar to casting, as it requires a similar exchange of knowledge.

1.2 Release and Change Process

The above mentioned challenges in additive manufacturing parts' design process and the common problematic design methologies employed in the industry make the utilsation of release and change processes in the context of advancing digitalisation in general even more important than in other manufacturing technologies.

Change and release processes are vital in the product lifecycle [10, Ch. 11.4] and can be seen as part of a digital thread [11] and the 3D Master [12] methodology. They ensure that manufacturing takes place on the right design [13], [14]. They are the starting point to ensuring traceability throughout the lifecycle of a product instance [15], [16]. As such, they are a cornerstone of Industry 4.0, related value chains [17], and are potentially even connected to technologies such as, e.g. the blockchain [18]. Traceability, also known as "Traceability 4.0" [19], is typically divided into tracking and tracing. The industry has incorporated this instrument to some extent and uses it, e.g. for quality assurance. Furthermore, the data of design (master data) and manufacturing codes are required to build specific digital twin frameworks [20] by using the digital shadow of production [21]

All the above is also valid for additive manufacturing (AM). The technology is even more complex than classic manufacturing technologies, e.g. turning and milling; therefore, the manufacturer should aim for good traceability. The additive manufactured item is the starting product for the subsequent machining and might contain a complex, topologically optimized structure [6], [22]. It is indicative of the technology's complexity that in a (German) textbook regarding the development methodology of AM [23], no word regarding a proper release process is mentioned.

This gap is more pronounced when considering change processes [24], [25]. For instance, if the raw part gets updated, the final machining must be reevaluated as well. An example would be the reduction of a hole's diameter (raw part); the final machining has to be adapted to avoid potentially damaging the tools. **Fig. 1** and **Fig. 2** show the raw and final parts, where the centre bore, marked in red, is machined.

All the arguments above consolidate the motivation that should lead the establishment of a proper release and change process in an organization.

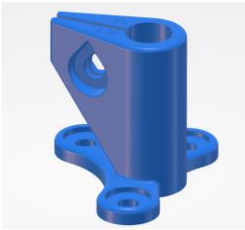

Fig. 1. Raw part

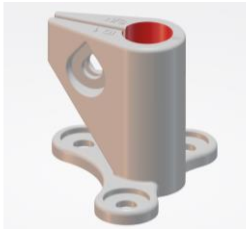

Fig. 2. Final machined part

2 Proposed Design and Release Process Description

As design and release processes and design practises can be an abstract topic that is prone to misunderstandings, an "ideal" design and release process (see **Fig. 3**) is proposed to act as a tool for both common understanding and for challenging the participant's design practises in their industrial environment. This "ideal" design and release process is developed through the collaboration and the exchange of knowledge and experience from the research groups for Product Lifecycle Management and Additive Manufacturing (AM) at the University of Applied Sciences. Hereinafter the "ideal" design and release process that is proposed to the survey's participants is explained.

Design for Manufacturing (DfM) and Design for Additive Manufacturing (DfAM) is key for modelling the raw part (1) and the final part (2). The process's prerequisite is that the engineers understand both additive manufacturing and classic manufacturing technologies. The raw part gets its unique part number for identification in the PLM, and the customers' unique article number for part identification is allocated (remains on the final part).

An associated copy (linked) of the raw part is used to define the final machining (2). This final part contains the related product manufacturing information (PMI) and is identifiable by a unique part number. When finalised, it gets released accordingly.

The preparation for manufacturing runs in parallel. On the one hand, the raw part gets exported (3), e.g. STL, and elements such as supporting structure and filler are defined in a respective slicing tool (4). On the other hand, the manufacturing of the final part is prepared in a CAM process (5). The material that needs to be milled is the difference between the raw and final parts.

Both manufacturing setups get released individually. The manufacturing and post-processing (6) of the raw part is conducted. That is the point in the process where the serial number is written on the part (e.g. engraved or lasered). Afterwards, the final part is manufactured (7). Note: With this process, it is also possible to design the finished model in the first step and the AM raw part afterwards (copy with link).

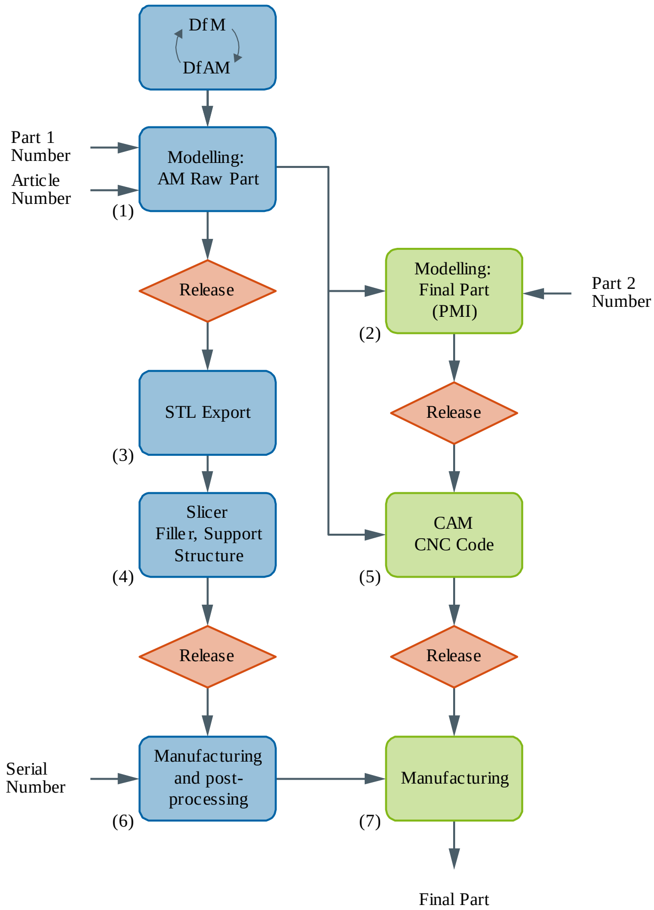

Fig. 3. Proposed design and release process for Additive Manufacturing

3 Survey And Results

3.1 Boundary Conditions

In total, 24 people who finalised the Certificate of Advanced Study (CAS) course Additive Manufacturing [26] have received the questionnaire. Three were from the same company, so only one of them answered the questionnaire.

Furthermore, two different networks have been approached: IBAM [27] and SAMG [28]. They have rejected approaching their members outside of their communication schedule. Therefore, the conclusions are based on the answers of 14 former CAS participants and two other contacts. In total, 16 answers constitute the sample. The response rate is 58 %. Considering that three people from the CAS came from the same company, 14 out of 22 companies have answered the questionnaire (64 % response rate).

3.2 Questionnaire And Answers

The following table lists the most relevant questions of the questionnaire, along with the respective possible answers and compiled results to grant a quick overview. The questions are aimed at evaluating and understanding the companys' data handling and utilisation as well as their understanding: {4} clarifies if design and manufacturing is within the same company, {7} to {10} explore the way of working to design AM parts, and {11} to {17} focus on the releas process.

Table 1. Relevant questions, related answers, and results

{4} Is the AM part manufactured in-house or by a supplier?	
In-house	81 %
By a supplier	19 %
{7.1} Do you design a model for the raw part (AM part) and a separate one for the final part?	
Yes	56 %
No	31 %
Different	13 %
Empty	0 %
{7.2} Are the models linked with each other (copy with link)? [Follow-up {7.1}]	
Yes	31 %
No	19 %
Different	0 %
Empty	50 %
{8.1} Do you apply product manufacturing information (PMI, "3D annotation"), e.g. tolerances, in your 3D model?	
Yes	19 %
No	81 %
Different	0 %
Empty	0 %
{8.2} If yes, are the PMI used digitally in the following processes as manufacturing and quality assurance? [Follow-up from {8.1}]	
Yes	19 %
No	0 %
Different	0 %
Empty	81 %
{9} Which fundamental data get created within your design process?	
Model of the raw part and model of the final part including product manufacturing information (PMI, "3D annotation")	13 %
Model for the raw part, model for the final part, and related drawing	38 %
Model of the final part and product manufacturing information (PMI, "3D annotation")	6 %
Model of the final part and related drawing	38 %
Other	6 %

{10} Which files are you managing in your product lifecycle management (PLM) system? Please select the related elements.	
Model for the raw part (can include PMI)	25 %
Drawing of the raw part	56 %
Export of the raw part, e.g. as STL format	19 %
File of the slicing tool (e.g. Magics)	19 %
Export of the slicing tool (machine code)	19 %
Quality assurance data of the raw part as e.g. measurements	38 %
Model of the final part (can include PMI)	75 %
Drawing of the final part	69 %
Machining code of the final part	6 %
Quality assurance data of the final part as e.g. measurements	13 %
{11} Which elements need to be released according to your release process?	
Model for the raw part (can include PMI)	19 %
Drawing of the raw part	44 %
Export of the raw part, e.g. as STL format	6 %
File of the slicing tool (e.g. Magics)	6 %
Export of the slicing tool (machine code)	6 %
Model of the final part (can include PMI)	44 %
Drawing of the final part	69 %
Machining code of the final part	6 %
{12} Are parts manufactured, e.g. for prototyping, without being released according to your release process?	
Yes	63 %
No	38 %
{14} Is there a differentiation in the release process between AM and conventionally manufactured parts (e.g. milling or turning)?	
Yes	19 %
No	81 %
{17} Would you like to apply this proposed release process, not considering the effort for its introduction?	
Yes	38 %
No	63 %

3.3 Cross-Comparisons

Table 2 shows three relevant cross-comparisons between two questions each. The first two comparisions provide insight on which participants would like to apply the proposed design and release process, while the third comparison shows if those companies that go to the trouble of applying PMI in their company also use it for subsequent processes.

In **Fehler! Ungültiger Eigenverweis auf Textmarke.**, the relevant cross-comparisons are listed. The first considers only those who manufacture in-house, while the second and third consider those who apply PMI.

Table 2. Cross-comparisons

{4} & {17} Liking to apply the proposed release process while production takes place today in-house	
Yes	46 %
No	54 %
{4} & {8.1} Liking to apply the proposed release process while using today product manufacturing information	
Yes	100 %
No	0 %
{8.1} & {8.2} Applying PMI (“3D annotation”) and using those further	
Yes	100 %
No	0 %

3.4 Bias

Bias, or survey error, is a common challenge in surveys and is discussed on related web tools [29] and internet pages [30], as well as in literature [31], [32]. The most common types of bias are [33]:

- Sampling bias
- Non-response bias
- Acquiescence bias
- Social desirability bias
- Question order bias
- Interviewer bias

This survey is primarily affected by the sampling bias and the non-response bias. The sampling bias occurs because only people with a certain degree of knowledge and experience in additive manufacturing or product lifecycle management have been approached (see chapter 3.1). But it does not matter as the survey aims to conduct a gap analysis between release and change management theory and its application in the industry. If the conclusion is that there is a significant gap, it is even more pronounced when looking at the whole industry. If there is no gap, the conclusions can only be drawn for the pinnacle in the industry. Therefore, relevant conclusions can be drawn despite this sampling bias.

Much the same applies for the non-response bias. The assumption is that the approached people who have not answered the questionnaire would not increase the rate of participants who have applied the design and release process.

4 Conclusions And Gap Analysis

Dissemination of additive manufacturing among participant companies:

- The people who answered work for large, medium, and small-sized companies. What the companies have in common is that only a few people are deeply involved in additive manufacturing technology, working in teams of 1 to 11 people per company. Only one answer from a large-sized company stated a number above this range: 20 people. Therefore, the conclusion is that additive manufacturing is still a niche technology.

- The average share of AM parts among all types (not quantity) of parts manufactured in a company is 3.5 %. This figure does not include entities such as schools or service providers focusing on this manufacturing technology. For example, one such excluded answer came from a company that exclusively offers the manufacturing of AM parts as a service. Thus, they claim to have a 100 % share of additive manufactured part types.

Dissemination of "design for additive manufacturing" and utilisation of optimised release processes and PMI among participant companies:

- The "design for additive manufacturing" has not yet been established throughout the industry to a particularly high degree. In many cases, the final part is designed, and the AM part is derived from it. Optimisation requires loops and potentially several releases and changes within the PLM. This is particularly true, if it is the production's task to figure out the raw part's design.
- Few companies/entities are using the full potential of modern design tools and related platforms. Typically, because the alternative ways of working seem more effortless. As a result, the traceability regarding the part identification (type) and the digital shadow of production [21] is not optimal.
- The classic setup that includes having a model and drawing(s) for a part is still the most common. Product manufacturing information (PMI) in the form of 3D annotations is only utilised in around 20 % of cases. Those who do use it are also using the information in subsequent production steps. The remaining 80 % are not exploiting this potential regarding digitalisation and Industry 4.0.
- Around half of the companies/entities see the proposed release process as beneficial. This ratio is slightly more pronounced by those who manufacture the AM parts in-house. It achieves 100 % among those that apply PMI in their workflow. Therefore, the conclusion is that the more digitalisation and higher integration are driven, the more applicable the release process is.

In conclusion, there is still a significant gap between the application and the potential of digitalisation and modern development tools in the still niche additive manufacturing industry. However, the responses from the companies that already exploit said potential show the benefits of a high degree of digitalisation as well and well implemented release processes. Those responses also confirm the benefits of the proposed design and release process.

As we aim to achieve a high level of digitalisation in the industry, the teaching and integration of the proposed release process will continue. The path taken with this PLM approach should be maintained, as it is vital for maintaining traceability, building the base for a digital shadow in production, and developing additive manufacturing and Industry 4.0.

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