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PROPOSAL OF PARAMETER CONTROL DESIGNATION SYSTEM OF ADDITIVELY MANUFACTURED PARTS

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Abstract: As additive manufacturing is getting more and more widespread, the need for a system regarding the technical documentation is getting more required. The tremendous amount of manufacturing parameters makes the performance of the part hard to assess. Same parameters are used with different names and there is no common knowledge of how these parameters affect the part precisely. We can find a serious amount of research data and results, but only a small portion of them is able to be compared because of the different measuring techniques or similar investigation of parameters. To be more effective with the data gathering, a systematic way of recording these aspects is needed. In this article we propose a robust way of recording information on technical drawings of additively manufactured parts. We also discuss the difficulties and future opportunities implemented by this method.

Keywords: *additive manufacturing, standardization, technical drawing*

1. INTRODUCTION

The conventional subtractive technologies have a significant effect on the design philosophies knowing the limits of the used manufacturing devices. Additive manufacturing (AM) methods differ from this approach by adding successive layers of material on top of each other. The demand for 3D printing has increased significantly during the last decade by reaching the required level of efficiency (Thompson, et al., 2016). Economic factors also allowed the development of the technology, since the production time decreased. The early technologies were responsible for rapid prototyping, but the approach has widened towards manufacturing final products as well. The processes are much more robust, because

AM methods do not require such complex tooling as the traditional manufacturing, making it easier if the nature of the product changes. The various AM technologies are SLS (Selective Laser Sintering), FDM (Fused Deposition Modelling), SLA (Stereolithography) and FFF (Fused Filament Fabrication).

The major issues with AM methods are the lack of proper common knowledge of the effects of parameters (Bhardwaj, et al., 2019). The number of studies characterizing these methods increased over the past couple of years, but they usually focus on mechanical properties (Albert & Takács, 2023). Designing for life cycles is still in the early stages compared to the conventionally manufactured parts in terms of survival safety. The nature of the technology requires the overall review and the standardization of the manufacturing parameters. The mechanisms regarding the layered structure still have not been fully covered yet. The knowledge could be essential for engineers to make the best decisions possible in terms of part utilization (Seregi, 2023).

In today's engineering work, Computer-Aided Design (CAD) has become a fundamental part. With the advancement of CAD systems, 3D models can now carry an increasing amount of information, which may be sufficient for the precise manufacture of the part. Therefore, the relevance of 2D technical drawing is questionable, although practice does not necessarily reflect this (Ficzere & Győri, 2016). During manufacturing, companies and professionals still use these drawings as fundamental documents, forming the basis for the production of the final component. Additionally, certain product documentation and descriptions may only appear in 2D format. As 2D drawings continue to prove their significance an increasing number of manufacturing methods are becoming more widespread and accessible. However, for some manufacturing technologies, creating drawings with the appropriate structure is challenging due to the peculiarities of the technology itself. AM technologies fall into this category. Despite the growing prevalence of AM, current drawing notations and standards are no longer sufficient. Therefore, the development of a new supplementary notation system is necessary. This new system has to comply to the present standards, so the integration has to be done with caution and reason. It must be compatible with Geometric Dimensioning and Tolerancing (ISO 1101), title blocks, manufacturing instructions and operation plans.

2. STANDARDIZATION OF PARAMETERS

In order to control the manufacturing conditions, it is essential to appropriately define the parameters themselves. Specifying what each of the parameters signify and its corresponding impact a necessary first step. Some of the parameters are defined partially in already existing standards (ISO/ASTM 52900). The parameters must not only be accurately described but also addressed for each branch of related additive manufacturing technology.

In the scope of our investigation, we are initially focusing on the FFF and FDM, in summary form Material Extrusion (MEX) technologies. To establish a comprehensive framework and workflow, it is essential to specify the manufacturing parameters which have great influence on the final state of the workpiece. We can distinguish primary and secondary parameters whose classification defines the impact on other parameters and on the entire quality of the workpiece. Additionally, we have the capability to distinguish between global and local parameters, a characteristic applicable to all secondary and the majority of primary parameters as it can be seen in Figure 1. Some of these parameters are defined by the machine itself and others can only be adjusted in the slicer settings (Kuznetsov, Tavitov, Urzhumtsev, Mikhalin, & Moiseev, 2019).

	Technical drawing	Operation plan
Printer parameters	Nozzle diameter Colour Model material Support material	Hotend temp Bed temp Chamber temp Print speed
Slicer parameters	Layer height Wall width Top/bottom layer width Infill pattern Infill density Orientation	Support control Local min wall width Local layer height Hole ovality (support/adaptive LH) Raster angle (infill, top/bot layer) Line width Ironing
Post-process	Surface finish Technology allowance (for milling or grinding) Insert/bushing placement and type Thread taping	

Figure 1. *Primary and secondary printing parameters sorted by parameters source and place of definition*

3. DOCUMENTATION

Not all parameters can be properly specified on the technical drawing, therefore, the manufacturing documentation needs to be supplemented with an operation plan, similar to the one used in machining. With this document, parameters that would require the modification of the views for their designation or those whose definition necessitates a more detailed textual explanation, can be precisely defined in a designated space created for this purpose. Only one literature regarding the drawing symbols for additive parts was found (Simion & Arion, 2016). The authors considered just a fraction of the parameters available in FFF processes, but this paper was the only reference for this work.

Technical drawing

Global parameters

In the technical drawing, we aim to designate global parameters using a table, as they significantly constrain several other parameters and the outcome of the workpiece. These are the variables most frequently adjusted. The parameters listed in the table are influenced by the first parameter, which is the type of AM technology. In this example, we are seeking solutions for FFF and FDM technologies, so their primary parameters are included in Table 1. The table serves a similar function to the tooth profile table found in workshop drawings of gears. While the teeth are not precisely drawn and dimensioned, they can be manufactured without issues because the table contains all the necessary data. In our case, this would result in a very long table, so we only include the primary parameters that are most frequently varied.

Table 1.
Primary parameters on the drawing

Additive manufacturing parameters		
Technology	FFF	-
Nozzle diameter		mm
Model material		-
Support material		-
Colour		-
Layer height		mm
Shell thickness		mm
Line width		mm
Infill pattern		-
Infill density		%

As it is presented in Figure 1, the wall, bottom and top layer widths are considered differently, but in the parameter table we merged them into the parameter called shell thickness. The reason for not specifically marking these is that a uniform thickness is expected on all cladding surfaces unless a different value is locally specified. Therefore, individual markings for these are not shown. Differentiating the wall thickness from the top/bottom thickness is presented in this work below. If there is any parameter that needs to be specified, a text like "Local parameters marked on view or operation plan!" could refer to the operation plan which contains the parameters.

Orientation

One of the first parameters that has the greatest influence on the performance of a part is the printing direction or orientation. To control the printing direction, we propose an orientation specification with a reference arrow used next to a view (Figure 2). The arrow has to point to the Z direction which is the slicing direction of all common printers. This sign is easily understandable and catches the eye on the drawing making it hard to miss. If there is a crowded drawing with multiple views on it, a text above the title block saying, "Manufacturing direction marked on view!" gives robust feedback.

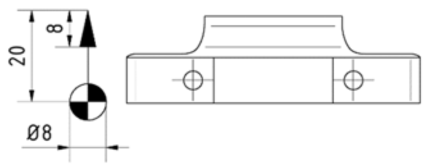


Figure 2. *Symbol to designate the orientation of the part*

Local minimum wall width

In certain cases, it is locally necessary to increase the number of walls. This can be attributed to technological allowance, drilling threads or threaded insert installing during post-processing, or simply to enhance the surface stiffness of a specific geometric feature. We propose to control the required wall width by extending the dimension of feature with a special symbol that can be seen on Figure 3. It is crucial to understand that the symbol represents the minimum width of walls required to a feature for special purposes. In Material Extrusion (MEX) technologies width of wall is constrained by the diameter of the nozzle and controlled with the material feed rate (extrusion rate measured in mm^3/s), which results in the line width parameter. As presented above, in Table 1 the nozzle diameter is defined, which combined with the line width gives the wall width sizes achievable (Kim, et al., 2022). Some slicers are capable of varying the line width to follow the contour of a section as close as possible, but this specific control option is not common.

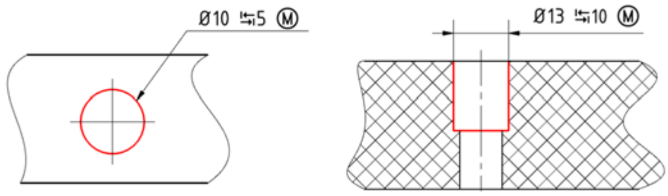


Figure 3. *Callout of min wall width (the red contour is optional on the technical drawing, but mandatory on the figure of the operation plan*

In Figure 3 we can see a circled letter M, which is a Geometric Dimensioning and Tolerancing (GD&T) specification meaning Maximum Material Condition (MMC). In this situation, used with the minimum wall width sign, we would like to emphasise that the number given is a minimum, meaning if it is necessary (because of the nozzle diameter or line width constraint) more walls have to be added to achieve the minimum desired value. This becomes particularly crucial when the intention is to tap a thread into a hole as post-processing. Insufficient wall thickness not only compromises the strength of the thread but may lead to breakage during the drilling process.
On the operation plan the minimum wall thickness can also be defined just by marking the feature and adding the parameter in the corresponding cell. It is up to the user to use the custom width and MMC mark or just marking the feature with a letter. (See the examples in Figure 4.)

Operation plan

Minimum wall width

As presented above we can define local minimum wall width on the technical drawing and the operation plan. To avoid the crowded drawing it seems to be a better solution to define these local parameters in the operation plan. This document also provides extra data entries, like a description where the reason of the specified parameter can be seen explained. (See in Figure 7.)

Support control

Specifying all the support parameters could be a separate document because of the number of subparameters it consists of. In this system we are trying to define only the parameters, which are crucial for the adequate manufacturing of the workpiece and not going to the lowest class of parameters only if necessary. The most commonly changed parameters of the support (besides the supported surfaces) are type, Z gap, support density, support number of walls, support pattern, interface density, interface pattern, interface height, XY distance from model, overhang angle. There can be situations when too much support is prohibited or have to be avoid. Prohibiting a support on a surface can be marked in a way showed in Figure 5. If a surface (for example a laying hole) needs to be supported, but we do not want to use too much support (starting from the build plate), support dead zones can be specified.

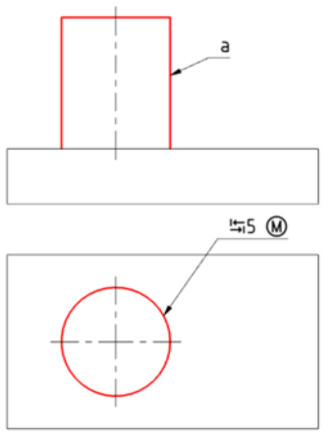


Figure 4. *Callout of min wall width without the size of the feature or parameter*

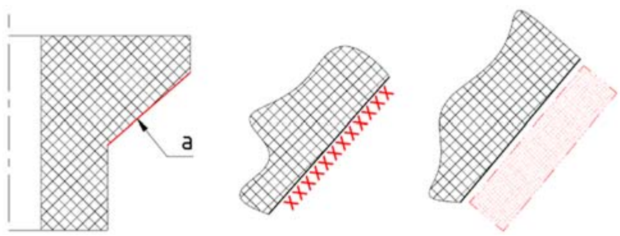


Figure 5. *Support controlled surfaces: marked with letter (left), marked with prohibition (middle) and marked with dead zone (right)*

Local layer height

The same way we mark the local wall width, we can designate the local layer height. In case of defining this parameter, two options have to be differentiated. We can set local layer heights section-wise through the whole part, or we can set it feature-wise (See Figure 6.). The goal of the two options is the same, the height difference between the height steps has to be considered. Having a larger height layer on the top of a much smaller one results a bad interlayer adhesion and porosity (Naresh, Raju, & Parveen, 2023). This is the same constrain we have to consider in case of the adaptive layer height.

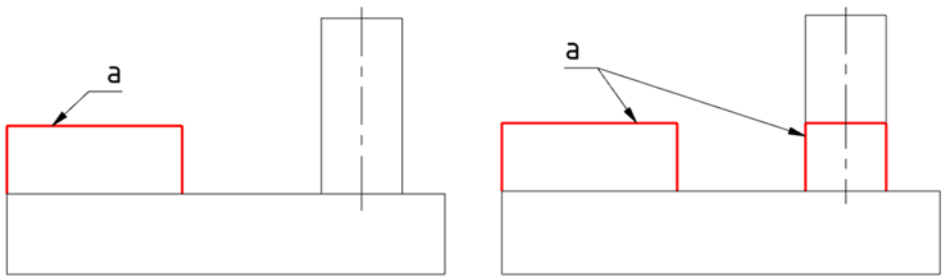
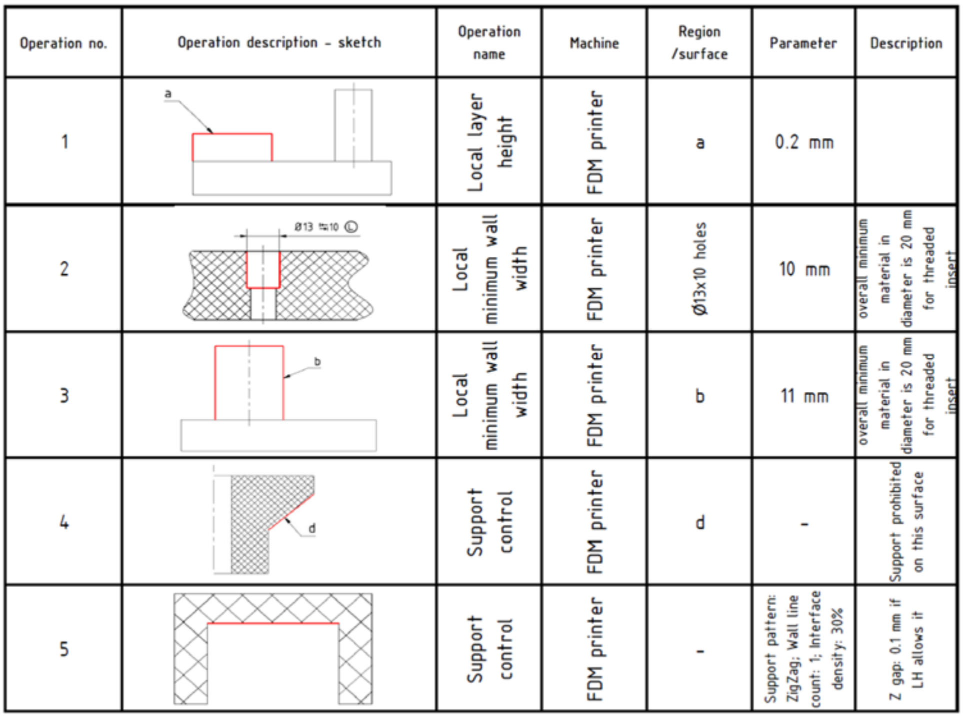


Figure 6. *The two options of variating the local layer height: feature-wise (left) and section-wise (right)*

In the presented system, a precise understanding of parameters and their interrelationship is fundamental. This holds true especially in the context of GD&T, where it becomes a necessary condition, as it is easy to specify tolerances that contradict each other. Therefore, a thorough knowledge of manufacturing parameters is a key consideration for a given technology. A straightforward example of this is specifying a layer height that the nozzle, due to its diameter and the hot end, cannot physically provide.

The provided table of the operation plan (Figure 7) functions as a collection of all local parameters. This way it is easier to detect contradicting parameter changes and gives a channel of information between the designer and the person who handles the slicer software. This version is work in progress, as we also need to collect parameters which the other types of AM technologies have. There can be some parameters which are also hard to define even in an operation plan.



Operation no.	Operation description – sketch	Operation name	Machine	Region /surface	Parameter	Description
1	a	Local layer height	FDM printer	a	0.2 mm	
2	Ø13 ⌴10 ©	Local minimum wall width	FDM printer	Ø13x10 holes	10 mm	overall minimum material in diameter is 20 mm for threaded insert
3	b	Local minimum wall width	FDM printer	b	11 mm	overall minimum material in diameter is 20 mm for threaded insert
4	d	Support control	FDM printer	d	-	Support prohibited on this surface
5		Support control	FDM printer	-	Support pattern: ZigZag; Wall line count: 1; Interface density: 30%	Z gap: 0.1 mm if LH allows it

Figure 7. *Examples of operation plan entries*

Additional elements

There are more parameters that we have not covered yet, but we collected more in Figure 1. Some of these parameters are already mentioned in connection with others, but some of them are left out totally. One of them is the raster angle. It is necessary to be mentioned because of its importance regarding the structural strength of the workpiece (Srinivasan Ganesh Iyer & Keles, 2022), (Sangaletti, Aranda, Távara, & García, 2024). We had difficulties finding a correct way of defining this angle and kindly ask the reader to provide their ideas if they have one. The latest idea was defining an angle on a view with a datum in the operation plan. If the orientation is fixed, then we can only move the part on build plate in the XY plane and rotate it around the Z axis. By rotating it, the orientation of the raster angle changes relative to the part, so we need a way of defining it on one of the part views in a robust way. As we could not provide a failsafe idea, we did not provide any graphics for this parameter.

Another problem is the dimensioning of the drawing. Using AM enables to create and design complex shapes, which are hard to fully define dimensionally. In case of the lattice structures a single unit parameter can be defined and the volume it fills, but with shapes that are generated with generative design or topology optimization, the freeform geometries cannot be described (Li, Yang, Bian, Zhang, & Wang, 2023). Even a human made geometry which is fitted for AM can be so complex, that it would take many views and make the drawing crowded and hard to read. Despite the problem, it would be crucial to establish a drawing or sizing method that allows for the definition of the entire workpiece without making the drawing too complicated.

4. SUMMARY

In this work, we addressed the manufacturing and technical documentation challenges arising from AM. Exploring the topic, we presented numerous proposals that could serve as guidance. Initially, we dug into parameters related to FFF and FDM technologies, classifying and organizing parameters. Subsequently, we recommended a notation system for the clear and understandable definition of these parameters. We plan to expand this system to other AM technologies in the future. At the beginning of the research, we took that into account there are already standards related to AM, but we did not encounter practical ones covering specific issues except for a paper (Simion & Arion, 2016) similar to our work.

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