Title:

Methodology for Part Building Orientation in Additive Manufacturing

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Introduction:

Additive manufacturing is a process increasingly used in automobile industry, aerospace [5], medical [4] and electronics. The principle constists in stacking layers of materials on the top of each other to create the desired part. Materials like metal, plastic or compiste can be used under powder, liquid or solid form for plentiful process assembly.

In additive manufacturing, a part will always be printed according to Z-axis but its positioning on the machine's tray, what we call part building orientation, is not unique. This choice made by user is not trivial and affects part's accuracy and surface finish generated by the staircase effect, the volume and complexity of supports created to support the part's overhangs during the printing and its building time and building cost.

Find a part building orientation which will permit to satisfy all criteria above is not an easy task. In fact, an orientation which gives a very satisfactory surface finish can lead to a long printing time and so a bigger cost. The methodology tackled in this article is intended to find a compromise between different criteria in order to help the user to position his part on the machine.

This paper will present a methodology for part building orientation in additive manufacturing. Through the selection of criteria used in this methodology and the explanations of them, an application will be approached. Finally, a conclusion will be discussed.

Methodology for part building orientation in additive manufacturing:

In this study, 4 criteria are considered: surface quality, volume of support, printing time and printing cost. To grasp the problematic and do not complicate the issue at the beginning, we selected four major criteria. The objective in our future works is to integrate other criteria.

For each criterion, an amount is computed, and weight is associated for each one. Weights are real included in $[0; 1]$, established by user, and allow to obtain a part orientation targeted by user's choice. The more the criterion is important to user, bigger is the weight. For example, user can choose to favour printing time rather than surface quality.

Then, an index is computed with the 4 criteria above.

$$Index = W_{SQ} \times S + W_{VS} \times V + W_T \times T + W_C \times C \tag{2.1}$$

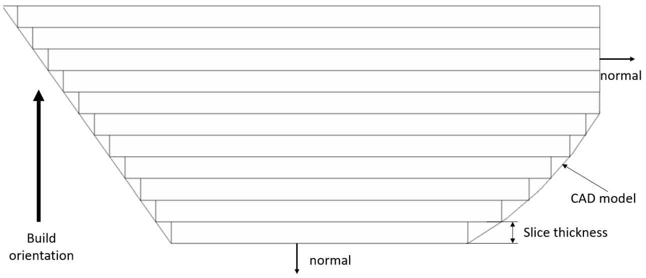

Fig. 1: Staircase effects in additive manufacturing

where:
W_{SQ}, W_{VS}, W_T *and* W_C are respectively weights for surface quality, volume of support, printing time and printing cost. And S, V, T *and* C are surface with bad quality, volume of support, printing time and printing cost.

Each amount obtained by a criterion is converted to a base 100, to avoid unit and change issues. An index is therefore calculated and associated for all positions chosen by user. Thus, the best orientation part will have the smallest index among all computed.

Positions are established by the following way: user selects faces which are important for him, faces which need a good surface quality. There will have as many tested positions as selected faces. Indeed, when a face is selected, the part orientation is the one where the face is perpendicular to the tray. For that, a normal average of the face is computed and is vertically oriented by rotations. All faces part are going through the same rotations and form the tested position. Thereafter, amounts for each criterion are calculated, which gives an index value for the position. The main reason why we place the selected face perpendicular to the tray is to avoid the staircase effect. Indeed, as you can see on Figure 1, a vertically oriented face is not affected by this issue contrary to overhang faces. Next sections explain how criteria are computed.

Surface quality:

Surface roughness has a big impact on surface finish for parts made through additive manufacturing. This roughness comes from different causes whose the main is the staircase effect. This effect is found on surfaces non-parallel/perpendicular to the XY-plane [3], basis for the print. Thus a good part orientation should minimize this kind of surface. Moreover, the layer thickness used during the print increases this effect with its big size. The angle between horizontal and material plays a part too, and this is usually accentuated when a support is needed to make the part. The roughness computation on the total part will give us an indication of the part's surface quality.

To evaluate the roughness on the part, we used works from J. Giannatsis and V. Dedoussis [2] on surface roughness estimation. They measured roughness by analysing a printing part with an inductive digital roughness gauge. Their works show that roughness is very high for angles include in $[10; 70]$ and $[145; 175]$ degrees. In order to have a good surface quality, surface amount with angles included in the ranges above need to be minimized. For this criterion, that is those surfaces which are computed.

Volume of support:

In most additive manufacturing processes, overhang need supports to be printed. In this algorithm, all overhangs with angle lower than 45 degrees are supported, Figure 2. Thus, a volume of support is

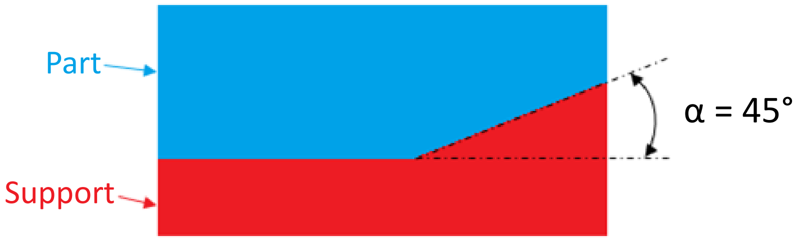

Fig. 2: Support according to angle

computed to represent this criterion.

Volume of support has a big impact on a printed part and should be minimised for a best orientation part. In fact, the more support you need to print a part and the bigger are contacts between supports and part, which impacts the surface quality and post-processing time needed to clean the part. Moreover, this needs more material to the printing which increases the printing cost and time. For this step the volume of support is computed as follow: it is the sum of projections on the tray of each triangle from the tessellation part with angle (between horizontal and material) lower than 45 degrees.

Printing time:

For this criterion, only printing time is computed, pre-processing and post processing time are not measured. This quantity is based on a formula developed by Di Stefano and Di Angelo [1]. Besides, to take into account total layers' deposition and total delay time between subsequent layers' deposition; they considered the complexity of the geometric model: the presence of holes and the complexity of layers' contours which induce unproductive times for tools movements. That's why layers' contours' depositions and repositioning tool are evaluated in the building time.

Printing cost:

For this criterion, a sum of various costs is made. It takes into account the volume of material needed to print both the part and support, energy used during the print and the part post-processing.

The cost of material needed for the print is the sum of part's volume and support's volume (deducted from support's criterion) multiplied by the cost of material in per unit. Then with the printing time criterion multiplied by the cost of energy, we deduce a cost for energy consumption. Lastly, the post-processing cost represents the cost needed to clean surfaces impacted by support. Therefore we summon all triangle's area from tesselation part with overhang lower than 45 degree with horizontal. This is equivalent to the total area needing support to be realized during the print, multiplied by a cost of cleaning, will give us an approximation of post-treatement cost.

Application and case study:

The application and the case study have been realised thanks to the project Taal, Figure 3. It is a research and developement project financed by CT CoreTechnologie. The goal is to develop a software for the preparation of CAD models for additive manufacturing. It allowed among other things to simulate roughness on part, create different kind of supports and lattice...

In this section, an industrial work piece has been tested, four differents positions (Figure 4) have been chosen and three cases with different values of weights have been analysed, Table 1. In the first case, Case 1, all weights are equals to 1, thus criteria values can be retrieved, Table 2. Then in Case 2, we chose to focus on surface quality and printing cost whereas in Case 3, printing cost then printing time are

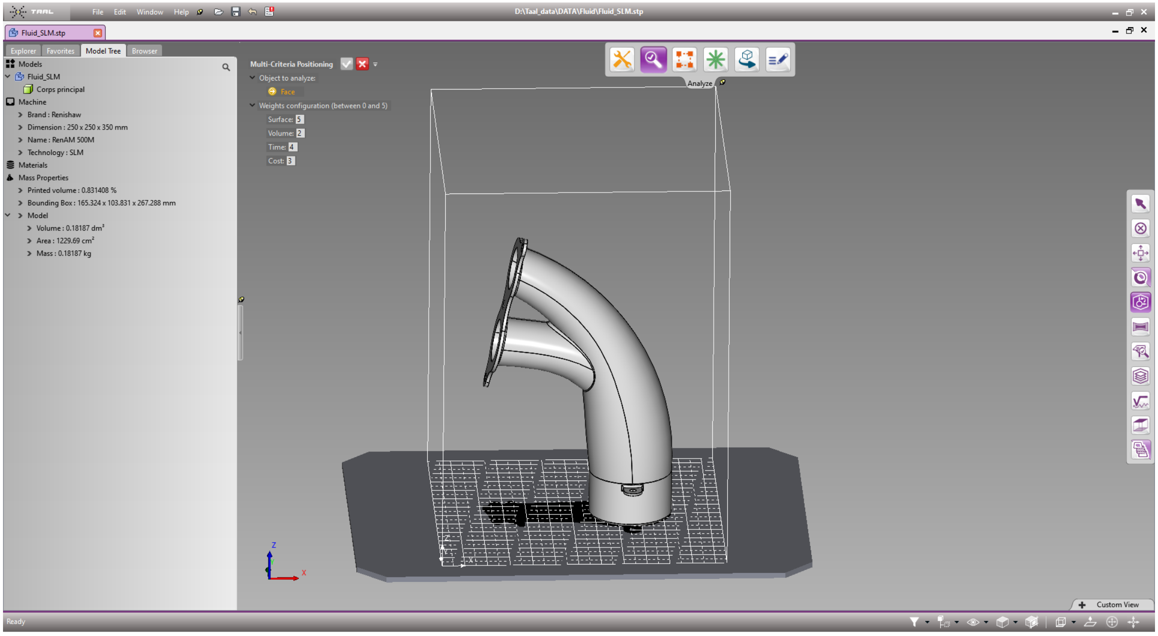

Fig. 3: Taal project

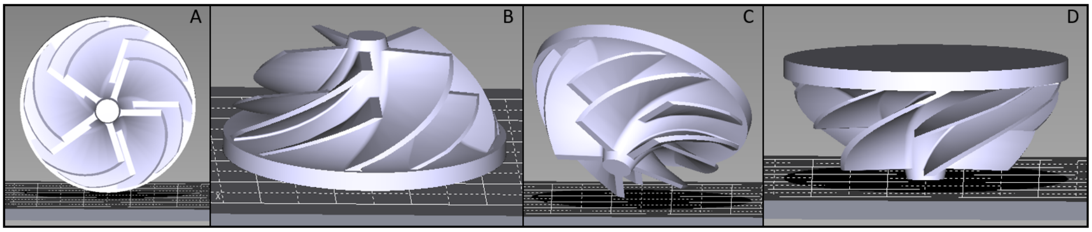

Fig. 4: Four positions tested for this part

mainly targeted. Results are therefore different and are presented in the array Table 3. In the two last cases, the best orientation found by the algorithm and the position 2 and 3 are different. This highlights weights power on the orientation of the part because they can change it. However, according to the parts and selected faces, we saw that a best orientation part can be the same whatever the weights. This is explained by the geometry of part, who can give the lowest criteria values for an orientation.

Conclusions:

A methodology is proposed for part building orientation in additive manufacturing process, it is based on four essential criteria which are surface quality, volume of support, printing time and cost. The algorithm allows to accentuate criteria according to the user's wish. Methodology has been applied on several industrial cases to verify the accuracy of the different criteria.

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Studied cases	Case 1	Case 2	Case 3
Surface quality weight	1	5	3
Volume of support weight	1	3	1
Printing time weight	1	2	4
Printing cost weight	1	4	5

Table 1: Weights for the three differents cases studied

Position	A	B	C	D
Surface quality	106,761	42.189	119.723	106.445
Volume of support	5.66E-05	5.15E-05	8.12E-05	6.23E-05
Printing time	654.092	1302.57	648.888	1237.72
Printing cost	81.2305	145.308	84.4017	140.441

Table 2: Criteria results for the Case 1 and the four positions

Position	A	B	C	D
Case 1	52.9982	59.7233	61.5802	71.4474
Case 2	195.801	193.2655	226.3941	250.2314
Case 3	163.51	213.8188	177.9374	241.3443

Table 3: Index values for the three cases and the four positions

the CIFRE agreement with ANRT.

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