

COB-2023-1883

FREE SOFTWARE TOOLS FOR ADDITIVE MANUFACTURING PROCESS PLANNING

Laureana Stelmastchuk Benassi Fontolan

Vinícius Rocha de Moraes Alves

Centro de Tecnologia da Informação Renato Archer, Rod. Dom Pedro I (SP-65), CEP: 13069-901 - Campinas, SP, Brasil

laureana.fontolan@cti.gov.br

vinicius.alves@cti.gov.br

Marcelo Fernandes de Oliveira

Centro de Tecnologia da Informação Renato Archer, Rod. Dom Pedro I (SP-65), CEP: 13069-901 - Campinas, SP, Brasil

marcelo.oliveira@cti.gov.br

Pedro Yoshito Noritomi

Centro de Tecnologia da Informação Renato Archer, Rod. Dom Pedro I (SP-65), CEP: 13069-901 - Campinas, SP, Brasil

pedro.noritomi@cti.gov.br

Abstract. *In Additive Manufacturing parts are fabricated adding material in a layer by layer procedure to compose an object from a digital 3D model, it comprises different technologies and materials, having great relevance in the aerospace, biotechnology, medical and automotive industries. The process planning for producing high quality parts is a challenge to overcome, each technology and equipment have a Computer Aided Manufacturing tool more aligned for its applications. The purpose of this study is to show a path towards unifying process planning in one free software option, thus increasing efficiency and lowering costs for software acquisition. The Renato Archer Information Technology Center is a Brazilian research center located in Campinas, state of São Paulo, it supports academic and industrial research with AM techniques such as Selective Laser Sintering, Electron Beam Melting, Fused Filament Fabrication and Polyjet through the 3D printing Open Lab (LAprint). As a free software, Blender's open code allows users to develop features and adapt it for specific applications, it is a digital modeling tool already established for graphical art and entertainment industry with very relevant production. Now it is becoming increasingly popular due to the cost-effectiveness for AM applications compared to the commercially available options. The software Blender was implemented for the process planning stage performing tasks such as mesh correction and analysis, model placement in the build volume of the equipment, and collision detection. All the tasks were performed for SLS - Sinteration HiQ (3D Systems), EBM - Arcam Q10 plus (GE Additive) and PolyJet Object Connex 350 (Stratasys) and Polyjet prior to slicing and fabrication. Some of the tasks can be performed directly in the graphical user interface (GUI) and others through python scripting. Further development is still in progress, and it aims to integrate tasks in the GUI using Python scripting only to automate processes. The procedure described in this study can reduce costs with software license acquisition, it contributes with the free software community and it can help other research centers and business with high transparency protocols in the Industry 4.0 context.*

Keywords: *Additive Manufacturing, Free Software, Process Planning*

1. INTRODUCTION

The LAprint is the Open Lab for 3D Printing in the Information Technology Center - CTI Renato Archer, a research and development center of the Brazilian Ministry of Science, Technology and Innovation (MCTI) founded in 1982. For Additive Manufacturing (AM), the laboratory provides different technologies and materials for medical, industrial and academic research collaboration requests. Some examples of collaboration are physicians through the Brazilian public health system SUS, a variety of enterprises through the EMBRAPII program, public and private universities such as Unicamp, USP, UNESP, PUC, UPM, among others. Generally, the applicant provides the digital models and the feasibility of the fabrication is evaluated according to the technology of interest, such as the following available at LAprint: Selective Laser Sintering (SLS), Fused Filament Fabrication (FFF), Electron Beam Melting (EBM) and Polyjet. In addition to collaboration requests, there are different ongoing and finished projects aiming at protocol optimization and applications *in loco* (Pereira *et al.*, 2012; Maia *et al.*, 2013; Campos *et al.*, 2014; Setti *et al.*, 2014; Saska *et al.*, 2018; Longhitano *et al.*, 2020; Fontolan *et al.*, 2022).

Apart from the various equipment and materials available, all AM technologies shares a core principle, parts are fabricated through the sequential addition of material in a layer by layer fashion (Volpato, 2017). For example, EBM

with Ti6Al4V and SLS with poliamide PA12 are both Powder Bed Fusion (PBF) technologies, for FFF with ABS or PEEK the materials in the form of a filament are fused and deposited upon a heated plate and Polyjet involves the photopolymerization of a liquid resin. The equipments and materials available at LAprint are crucially different from one another, yet they share the same core principle for fabricating parts by adding layers. Each possibility for AM has advantages and disadvantages depending on the part to be fabricated, ideally the 3D model should be planned according to the specific technology and material it's going to be fabricated with, frequently the applicants need further help to adapt or even make new versions for the 3D model to be suitable for AM. Once the model is ready, it has to pass mesh quality tests otherwise most of the slicing softwares won't be able to process it. When multiple models have to be fabricated, they can be grouped together in the same process and the final nesting of the parts is called "*the build*". The disposition of the parts involves rotating and translating the models inside the volume available for construction and those operations are fundamental for part quality. Since the position of the part in relation to the layer consolidation direction will affect intrinsically the structure of the fabricated object, the process planing needs to be reported to the applicants for them to analyse which portions of the object might have a worse performance and if it is still suitable for the intended application.

To achieve good quality parts with reproducibility, besides equipment and materials, all software involved in the process must be reliable as well. Commercial equipment usually are attached to their own proprietary machine control and slicing softwares, however, for process planning, cooperations can established with another companies specialized in software development. For example, EBM equipment Arcam Q10 plus have a specific functionality into Materialize Magics for process planning, CreatBot PEEK 3000 makes use of Prusa Slicer for process planing and slicing, each equipment will have their own set of softwares for different parts of the process. The use of alternative software for slicing or machine control is usually impracticable since each equipment has it's own proprietary setup for parameter strategy, many selling individual packages for new profiles. Open parameter equipment is of great interest for research and the number of companies providing it has grown, companies like Freemelt, Wayland Additive and Renishaw offer open parameter equipment for metal AM. Whereas slicing and machine control are challenging in terms of software versatility, modeling and process planning are AM stages where software choice is abundant. Successful adaptation can lead to a refined application of the software to local needs.

In summary, for an object to be fabricated by AM there are four main steps: a suitable 3D model must be provided through Computer Aided Design (CAD); this model is subjected to Computer Aided Manufacturing (CAM) which involves process planning with machine parameters and the generation of coordinates for the layers to be consolidated (slicing); equipment operation and; post-processing. The aim of the present study is to optimize the second stage of AM fabrication, the process planning. The following sections will present which routines can be optimized by the methodology proposed for the equipment available at LAprint.

2. METHODS

The software Blender (Blender Foundation, Netherlands) was elected to be the base for development of a free software alternative to AM process planning. Table 1 shows the softwares available at the LAprint used for validation. The mainly used Blender add-ons were STL, Bool Tool and 3D Print Toolbox (Blender, 2023).

The digital models were manufactured using Selective Laser Sintering (SLS), Electron Beam Melting (EBM), Fused Filament Fabrication (FFF) and Polyjet™ with Sintertation® HiQ™ (3D Systems), Arcam EBM Q10plus (GE Additive), Fortus 400mc (Stratasys) and Object Connex 350 (Stratasys), respectively. The Powder Bed Fusion (PBF) technologies used poliamide PA12 for SLS and Ti6Al4V grade 23 for EBM, FFF used ABS-M30™ and Polyjet™ used Vero™ resin.

Table 1. Softwares used for AM at LAprint.

	SLS	EBM	FFF	Polyjet
Process Planning		Materialize Magics 22 and Blender 3.5		
Slicing	Build Setup 3.42	Build Assembler 33.2.88	Insight 9.1 and CreatWare 7.0.2	Object Studio 9.2.8.3
Machine Control	SLS System 3.42	EBM Control 5.2.50	Control Center 9.1	Connex 350 37.2.0.23272

3. RESULTS

Process planning involves arranging models inside the simulated equipment building envelope in a manner that most favors the fabrication of the object. Optimal results depends on positioning the object according to it's final application and the AM technology used to produce the part. To explore the use of the software Blender to process planning for the AM technologies available at the LAprint, the routines to be optimized are presented in 3 sections, mesh correction and analysis, model placement and file importation/exportation.

3.1 Mesh correction and analysis

For a digital 3D model to be fabricated by AM, it needs go through verification, it requires the professional to achieve mesh parameters not usually required for other 3D modeling applications, such as graphical design or animation. Regarding the mesh quality, some criteria can be verified such as non-manifold regions and element intersections. Non-manifold detection shows open regions of the mesh, where the vector field of normals on the surface that describes the model is somehow interrupted, leaving non-manifold edges. Blender shows face orientation based on the surface normals direction and displays red for everything inside the model and blue for the exterior as shown in the Figure 1.

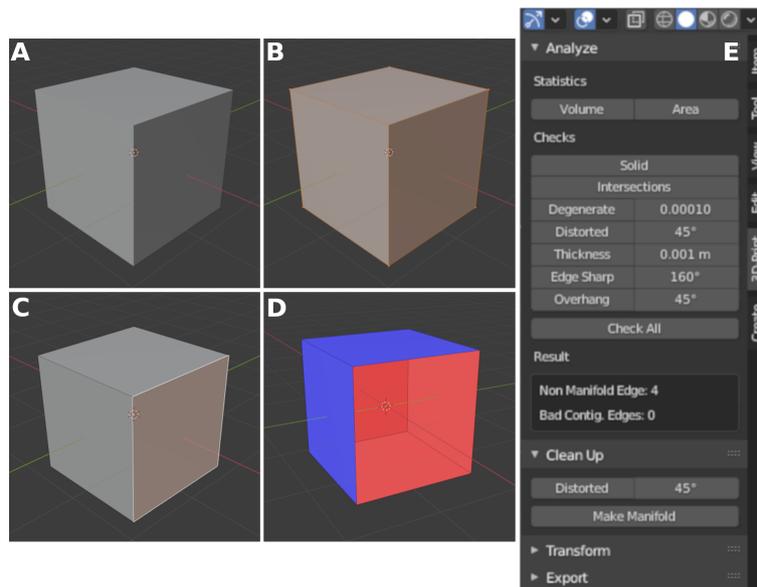


Figure 1. Non Manifold detection using Blender. (A) A cube mesh in the Blender's Object Mode; (B) Blender's Edit Mode showing vertices; (C) Selection of a face to be deleted; (D) Demonstration of the cube with the deleted face under the enabled Face Orientation tool colors; (E) Blender's 3D Print Tool Box add-on non-manifold edge detection feature.

For detecting element intersections, two cubes were generated, superposed and grouped together. The grouping procedure does not integrates the meshes of the two objects such as a Boolean operation would and objects grouped together as if they were one can cause problems during process planning usually by element overlapping detection. The 3D Print Tool Box add-on also detects intersections and depicts each element involved to facilitate the manual correction when necessary, Figure 2 shows defects detection using the add-on. In an intersection situation, ideally the parts should be separated and united again or dealt with by carefully reconstructing the mesh by hand or using the Remesh modifier.

The routine of the LPrint hardly deals with simple models such as cubes, thus it is important to evaluate more complex geometries for mesh evaluation and correction. The geometries selected for analysis are Triply Periodic Minimal Surface (TPMS) structures generated externally in the Free Software MathMod and loaded in Blender for evaluation. Figure 3 shows a gyroid TPMS model initially with non-manifold issues as it was loaded in Blender and the Solidify modifier was used to generate a second shell of elements to close gaps and hide internal faces that shouldn't be exposed. The thickness of the shell can also be chosen as it better fits the model's final application.

After mesh correction in Blender, the models were validated using software Magics 22 tool Fix Wizard. All TPMS models were effectively corrected in Blender using the 3D Print Tool Box add-on and the Remesh modifier which outputs a mesh corresponding to the volume of the original mesh when selecting the Voxel option, the selected voxel size in the object space used for volume evaluation was 0.1 mm.

3.2 Model placement

3.2.1 Volume boundaries

The building volume varies from one equipment to another, to unify the process planning in different machines using the same software, a set of profiles should be generated. To generate the profiles, constraints such as the maximum building volume and the minimum distance between parts were established. Each profile must be accessed through a Blender startup file designated to a given machine. For example, the Sinterstation HiQ has a designated "startup.blend"

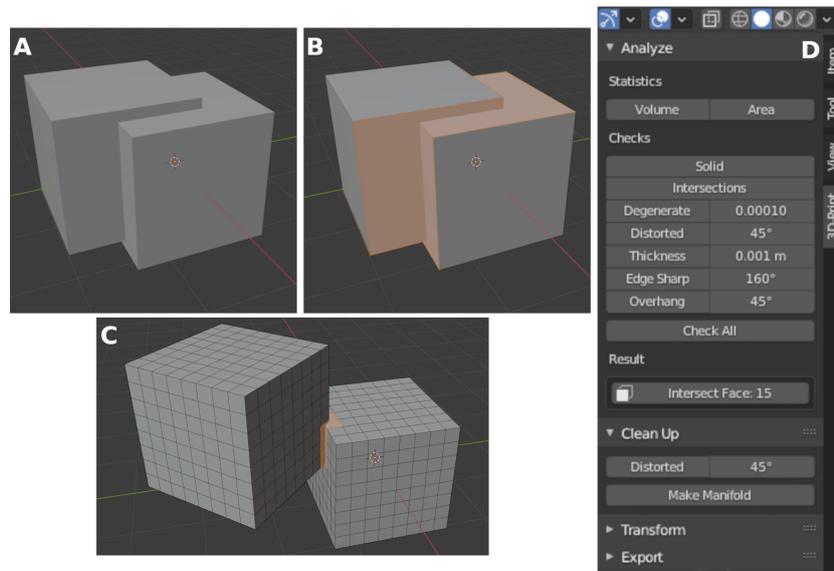


Figure 2. Blender 3D Print Tool Box add-on intersection detection feature. (A) Two cubes grouped together; (B) intersection detection; (C) Subdivision depicting the finer detection of the mesh elements involved in the intersections; (D) The 3D Print Tool Box add-on window showing the number of intersections detected after mesh subdivision.

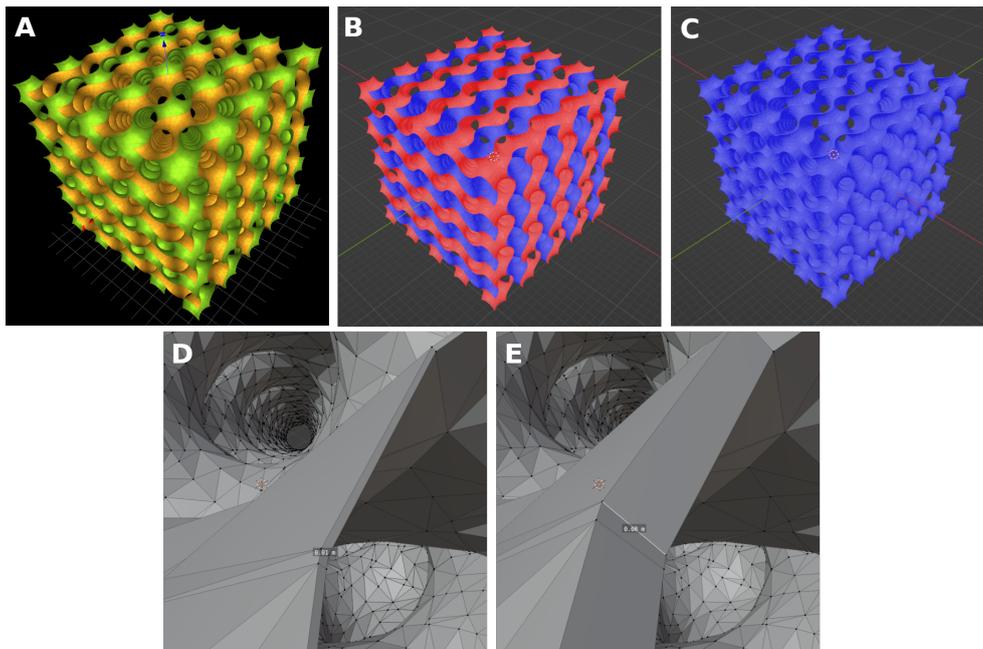


Figure 3. Generation of TPMS structure using the MathMod software. (A) Gyroid structure visualization on MathMod software; (B) exported OBJ file loaded on Blender showing face orientation; (C) fixed mesh with the Solidify modifier and; different thickness values for this modifier with measured distance values for 0.1 (D) and 0.8 mm (E).

file in a relative path under a sub-folder. Table 2 shows all technologies studied for process planning with the methodology proposed for simulating each equipment building volume using Blender.

3.2.2 Collision detection

The composition of models organized inside the building envelope must be organized in such manner that each part doesn't collide to others on the vicinity. Moreover, they must be apart from each other in a distance determined by the part clearance. Preliminary results using Blender's Python Console an interactive programmatic console for advanced editing and script development, and Info with log of operations, shows promising use of Blender and Python scripting for collision detection and nesting of parts inside a determined building envelope. For faster testing, the following command line option was used to run Blender without the Graphical User Interface (GUI) on Arch Linux system:

Table 2. Equipment characteristics used for profiling in Blender.

		Bounding Volume	Dimensions (mm)	Part Clearance (mm)	
SLS	Sinterstation HiQ	box	x 336, y 280, z 440	2	
	Sinterstation 2000	cylinder	xy 127, z 300	2	
EBM	Arcam Q10+	box	xy 200, z 180	2	
	Fortus 400mc	box	x 336, y 280, z 440	4	
FFF	CreatBot PEEK300	Single	box	xy 300, z 400	4
		Dual	box	x 240,y 300, z 400	4
	ZMorph	box	x 235,y 250,z 165	4	
Polyjet	Connex 350	box	xy 342, z 200	2	

`blender -background file.blend -collision_detection.py`

where, blender is called on background running the script "collision_detection.py" based on BVH tree structures for proximity searches and ray casts on geometry for the models in the "file.blend".

Efficient collision detection routines facilitates part position checking while composing the final build file. It is important to show the portions of the models colliding with each other to rearrange the models as necessary. Ongoing development to achieve this visualization feature will help professionals to fine tune model positioning inside the building envelope.

3.3 File importation and exportation

File importation and exportation in Blender makes it possible to work with a variety of file extensions and batch generation of models. To decrease the size of the final models Blender Decimate modifier can be used to reduce the number of elements describing a model surface. File size can be a challenge to process planning as well, unnecessarily heavy projects can delay part fabrication by requiring more time to process data and better computing hardware.

4. CONCLUSIONS

The protocol proposed focused on optimizing AM in the 3D Printing Open Lab at the CTI Renato Archer, where it can accelerate the manufacturing of parts for research requests and complete them more efficiently. Moreover, as a prominent center for AM in Brazil, the LAprint guided tours improve visibility of AM technologies and applications as well as suggesting free software protocols for new companies interested in cheaper, more versatile and free software solutions.

Although Blender has a steep learning curve, it is a more versatile software and it has great perspective for AM process planning besides 3D modeling in Design for Additive Manufacturing (DFAM). Blender was able to achieve mesh correction with results similar to the previous software solution used at LAprint and will be further investigated to improve collision detection and nesting routines for composing models inside the building envelope of the equipment included in this study.

Besides the first tests were carried out using Linux systems, it was also successfully tested in Windows systems as Blender is a multi platform software. The procedure described in this study can reduce costs with software license acquisition, it contributes with the free software community and it can help other research centers and business with high transparency protocols in the Industry 4.0 context.

5. ACKNOWLEDGEMENTS

This study was supported by the funding agency CNPq.

6. REFERENCES

- Blender, 2023. "Add-ons". In *Blender 3.5 Manual from the Blender Documentation Team*. URL <https://docs.blender.org/manual/en/latest/addons/index.html>.
- Campos, B., Calefi, P.S., Ciuffi, K.J., de Faria, E.H., Rocha, L.A., Nassar, E.J., Silva, J.V.L., Oliveira, M.F. and Maia, I.A., 2014. "Coating of polyamide 12 by sol-gel methodology". *Journal of Thermal Analysis and Calorimetry*, Vol. 115, No. 2, pp. 1029–1035.
- Fontolan, L.S.B., Polly, D., Machado, L., Oliveira, M. and Noritomi, P., 2022. "Emprego de Software Livre para Modelagem, Análise, Correção de Malha e Planejamento de Processo para Manufatura Aditiva (in portuguese)". In *Anais do VII Encontro Nacional de Engenharia Biomecânica*. ABCM.
- Longhitano, G.A., Candido, G., Ribeiro Machado, L.M., Neto, P.I., de Oliveira, M.F., Noritomi, P.Y., Mais, F.G., de Paula Souza, V.L. and Lopes da Silva, J.V., 2020. "3D-printed valves to assist noninvasive ventilation procedures

- during the COVID-19 pandemic: a case study”. *Journal of 3D Printing in Medicine*, Vol. 4, No. 4, pp. 193–202.
- Maia, I.A., de Oliveira, M.F., Neto, P.I., Pereira, F.D.A.d.S. and da Silva, J.V.L., 2013. “Exploração dos recursos de impressão 3D para peças especiais”. *7º Congresso Brasileiro de Engenharia de Fabricação*, p. 9.
- Pereira, T., Silva, M., Oliveira, M., Maia, I., Silva, J., Costa, M. and Thiré, R., 2012. “Effect of process parameters on the properties of selective laser sintered Poly(3-hydroxybutyrate) scaffolds for bone tissue engineering: This paper analyzes how laser scan spacing and powder layer thickness affect the morphology and mechanical properties of SLS-made scaffolds by using a volume energy density function”. *Virtual and Physical Prototyping*, Vol. 7, No. 4, pp. 275–285. ISSN 1745-2759, 1745-2767.
- Saska, S., Pires, L.C., Cominotte, M.A., Mendes, L.S., de Oliveira, M.F., Maia, I.A., da Silva, J.V.L., Ribeiro, S.J.L. and Cirelli, J.A., 2018. “Three-dimensional printing and in vitro evaluation of poly(3-hydroxybutyrate) scaffolds functionalized with osteogenic growth peptide for tissue engineering”. *Materials Science and Engineering: C*, Vol. 89, pp. 265–273.
- Setti, G.d.O., de Oliveira, M.F., Maia, I.A., da Silva, J.V.L. and Joanni, E., 2014. “Correlation between mechanical and surface properties of SLS parts”. *Rapid Prototyping Journal*, Vol. 20, No. 4, pp. 285–290.
- Volpato, N., 2017. *Manufatura Aditiva: tecnologias e aplicações da impressão 3D*. Edgard Blucher Ltda, São Paulo, Brasil, 1st edition. ISBN 85-212-1150-3.

7. RESPONSIBILITY NOTICE

The authors are solely responsible for the printed material included in this paper.