# THE IMPACT OF THE G–CODE FLAVOUR SELECTION IN FFF

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**ABSTRACT:** Fused Filament Fabrication has become one of the most popular additive manufacturing technologies due to many hardware options and materials at affordable prices. A reason for its success is the open-source status of the technology. This allowed both professionals and amateurs to contribute to the development of material extrusion technology. Furthermore, a wide range of available equipment brought slicing software developers to improve the user experience by expanding the equipment library and making the interface user-friendly and intuitive. In order to successfully print a part, the printer's firmware must interpret a compatible G-code file generated by a slicer. For this reason, each slicing software has multiple G-code flavours available to match the equipment. This paper aimed to evaluate the influence of all G-code flavours available in Cura slicing software by using a benchmark model. The evaluation refers to the resulting models' G-code characteristics analysis and print quality. The results show that the printed models' quality depends on G-code flavour and equipment.

**Keywords:** G-code flavour; Firmware; Slicing software; G-code interpreter; Fused Filament Fabrication

## 1. INTRODUCTION

Nowadays, Additive Manufacturing (AM) technologies are largely used in various fields of activity such as automotive, medicine, electronics, research, and development or education (Gibson et al., 2015). Even if AM family holds a considerable number of technologies, most people refer to them as 3D Printing (Kokovic, 2017). Regardless of

the AM technology, all of them produce parts layer by layer based on 3D data, which is generally called a mesh (Gibson et al., 2015).

Fused Filament Fabrication (FFF) is one of those technologies, and due to the affordable equipment and the great variety of materials (e.g., thermoplastic material blend, colour, properties) available on the market, it has become one of the most popular 3D printing technologies (Oztan et al., 2019). The material is sourced from a spool of filament, then melted and forced through a nozzle, and deposited layer-wise based on tool path instructions (Gardner et al., 2019). Those are generated in the printer's software (i.e., slicing software) as geometrical code (G-code). Each G-code is generated for the printer's hardware specification and firmware (Jones et al., 2011).

Depending on the manufacturers of the 3D printers, the firmware architecture can vary, having a G-code interpreter that accepts only one or more G-code types (flavours). For example, Cura from Ultimaker, along with other software (e.g., Simplify 3D, Fusion 360, Prusa Slicer), is an open-source slicer that is compatible with many 3D printers (e.g., Ender, Prusa, Anycubic), and for this reason, it has multiple G-code flavours options available.

Considering that there is no information available regarding the flavours and their influence on the printing process at the current state of the art, this research aimed to find the impact of G-code type in the 3D printing process and geometrical product specification. Furthermore, it is interesting to find out if the G-code type can influence the printing time and other characteristics of the 3D printed parts.

## 2. G-CODE FLAVOURS AND TESTING METHODS

### 2.1 *General considerations*

In general, any 3D printing process creates models based on the same workflow, as presented in figure 1. The majority of open-source FFF 3D printers build models based on a numerical control list of commands. In order to obtain the G-code, the mesh model is uploaded into slicing software. Therefore, a compatible 3D printer has to be selected from a list, along with the type of algorithm (flavour) that will generate the G-code file. After positioning the model and parameter selection (e.g., material, speed, layer height, temperature), the mesh model is sliced, generating the G-code. Then the G-code is loaded onto the physical printer, depending on the model, via a USB port or from a memory card. Finally, the firmware (software that runs on the printer's microcontroller) interprets the compatible G-code line by line and starts to execute.( Horvath, 2014, Horvath & Cameron, 2015).
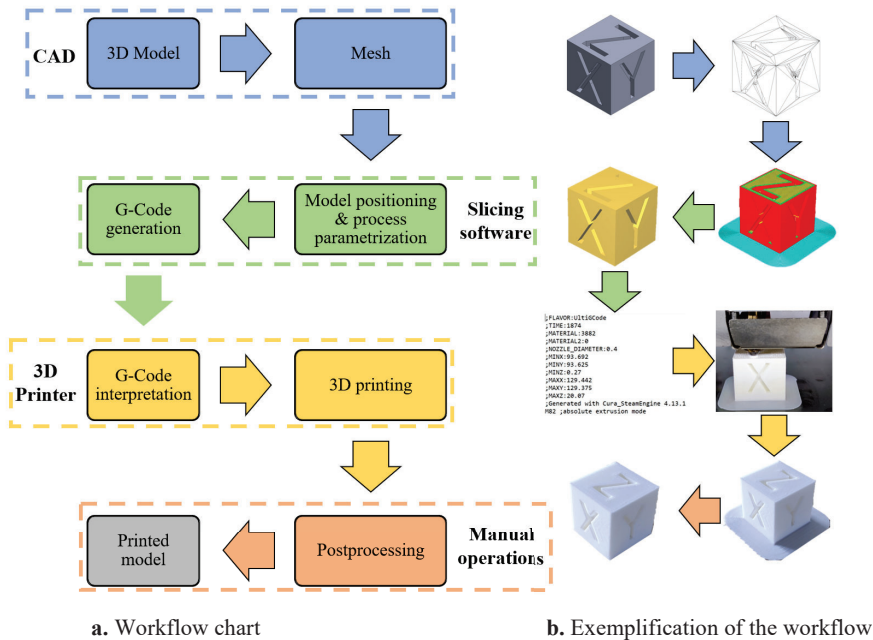
**a.** Workflow chart          **b.** Exemplification of the workflow

**Figure 1.** Workflow of FFF 3D printing process

As a 3D printer, for this research the Ultimaker 2+ with the firmware version 3.3.0 was selected, and as a slicing software, Ultimaker Cura, version 4.13.1. This software is compatible with approx. 400 3D printers and can generate nine types of G-codes (flavours). These flavours and a short description of each are presented in Table 1. Conventionally, for the Ultimaker 2+, the manufacturer recommends to use the Ulticode flavour to generate the G-code.

**Table 1.** Description of G-code flavours available in Cura 4.13.1

| No. | G-Code flavour | Brief description |
|---|---|---|
| 1 | Marlin | -considered as the default g-code flavour |
|   |  | -most popular firmware and the basis of most alternative firmwares |
| 2 | Marlin Volumetric | -a variant of Marlin where the extruded quantity in cubic millimeters is specified via extrusion commands |
| 3 | RepRap | -flavour focused on supporting printers that evolved from the RepRap project |
| 4 | Ultimaker2 (Ulticode) | -flavour intended for the Ultimaker 2 family |
|   |  | -it doesn't allow to control the material-related settings |
| 5 | Griffin | -flavour for modern Ultimaker printers, UM3 and newer. |
|   |  | -g-code starts with a large header of metadata (e.g., name of the print job, duration of the print, starting temperature) |
| 6 | Repetier | -flavour aims at Repetier 3D printers |
|   |  | -mimics the output of Repetier slicer |
| 7 | Makerbot | -flavour intended for Salifish based firmware |
|   |  | -used for original Makerbot printers |
| 8 | Bits from Bytes | -flavour targets Bits from Bytes printers which had their own custom firmware |
| 9 | Mach3 | -flavour that generates a G-code similar to the ones used in CNC milling |

## 2.2 TESTING METHODS

In order to evaluate the influence of each G-Code flavour on the geometrical product specification, a test model was chosen. This is the XYZ calibration cube, a widely used benchmark model in the 3D printing community. The cube is 20x20x20 mm and has three marks with the letters X, Y, and Z with different angles and a depth of 2mm, representing the cartesian coordinates (see figure 2). The selected filament was a white color polylactic acid (PLA), with a diameter of 2.85 mm from Aprinta Pro. The depth and the angles of the letters make the printed part subject to bridging and ghosting.
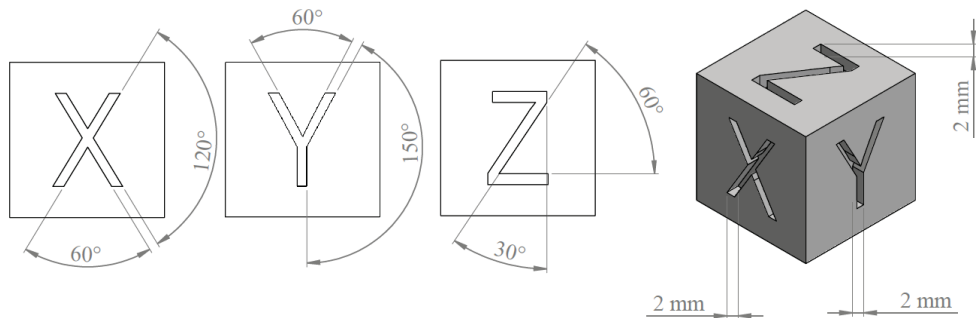


**Figure 2.** XYZ calibration cube specifications

In order to have comparable results, for each flavour a default printing setting profile generated by Cura was preset. The main parameter values are presented in table 2. The model was positioned centrally on the building plate with an orientation respecting the XYZ marks for each print.

**Table 2.** Normal profile parameters values.

| Profile name | Layer height (mm) | Infill (%) | Support | Adhesion | Brim lines (No.) | Print speed (mm/s) | Printing temperature (°C) | Build plate temperature (°C) |
|---|---|---|---|---|---|---|---|---|
| Normal | 0.15 | 30 | No | Brim | 23 | 60 | 200 | 60 |

Each resulting model will be evaluated based on six criteria. Those are file size, number of g-code lines, printing time, weight, ghosting, and general surface aspect. The file size, the number of g-code lines, and the printing time will provide an overview of the algorithm's performance. The flavour that requests the smallest number of tool paths will be considered the most efficient. By scaling the part, the real weight of the part can be compared with the slicer estimation. Ghosting is a visual defect of the printed part that creates fades (patterns) of an existing mark. It is usually caused by high printing speeds and vibrations that appear in the machine. The general surface aspect was considered because aesthetics are essential to the final product. Based on a visual inspection of the printed part, the criteria that can't be quantified will get a score between 1 and 5 (being the best).

## 3. RESULTS

From the resulting g-code files, two of them, Bits from Bytes and Mach3, failed from the beginning because the firmware of the Ultimaker 2+ could not interpret the flavours. The remaining prints were evaluated according to the methodology described in the previous chapter.
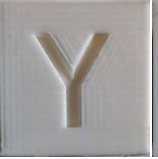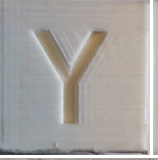
There are no significant differences regarding the file size, number of lines, and printing time. On average, the resulting file size was ≈653 KB and had a number of lines of ≈ 23042. By analyzing the g-codes, it was observed that the header and the footer of the instructions were written in distinct styles. For example, the Griffin flavour contains more metadata than the others. In the case of noninterpretable flavours, Bits from Bytes generated a set of instructions with a size of 1.014 KB containing 76031 lines, while Mach3, has a size of 652 KB and 23042 lines. Regarding the estimated printing time, all flavours had ≈1875 s. All compared data are presented in table 4.

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The dimensional accuracy of the resulting specimens was evaluated using a digital caliper. For each side, three measurements were taken. For the XY dimensions, it can be observed that the Repetier flavour generated a model with 20.02 mm on the X side and 20.06 mm on the Y side. From the Z dimensional, the best results were achieved by the Griffin flavour, having 20.14 mm.

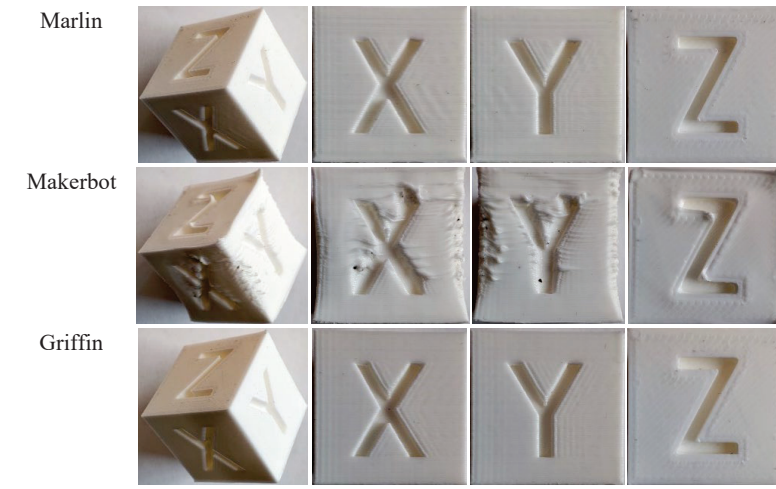Regardless of the used flavour, the slicer estimated a usage of 5 g of filament for the benchmark model and printing adhesion helpers. As shown in table 4, the weight closest to the estimation was Ulticode, having 4.8 g. On the other hand, the smallest quantity of material was used by the Repetier flavour, with 4.56 g, and the biggest by Marlin Volumetric, having 8.84 g. This difference in weight can be explained by different values of hidden parameters in the basic printing mode, such as layer width, extra line count, connecting fill lines, and how each flavour's algorithm interprets these parameters.

Ghosting defect was visible on all the printed models, as seen in the captions presented in table 3. The least noticeable ghosting was obtained for Ulticode and Griffin flavours. On the other hand, the most visible one was from Marlin Volumetric.

**Table 3.** Printed parts – visualisation of seven flavours

| Flavour name | Isometric view | X view | Y view | Z view |
|---|---|---|---|---|
| Ultimaker2 (Ulticode) | | | | |
| RepRap | | | | |
| Repetier | | | | |
| Marlin Volumetric | | | | |

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Regarding the general surfaces' aspect, the most aesthetic models were Ulticode and Griffin, followed by RepRap, Repetier and Marlin. The poorest surface quality was obtained for Marlin Volumetric and Makerbot which showed heavy warping defects. This defect can be caused by improper cooling settings, high printing speeds, and vibrations. Overall, Ulticode (also recommended by the manufacturer) and Griffin obtained the best results.

**Table 4.** Results score

| G-Code Type | File size (KB) | Lines (No.) | Printing time (s) | X/Y/Z dimensions (mm) | Weight (g) | Ghosting | General surfaces' aspect |
|---|---|---|---|---|---|---|---|
| Marlin | 652 | 23047 | 1875 | 20.03/20.09/20.2 | 4.73 | 2 | 3 |
| Marlin Volumetric | 660 | 23044 | 1874 | 20.34/20.44/20.45 | 8.84 | 1 | 1 |
| RepRap | 652 | 23045 | 1875 | 20.03/20.09/20.22 | 4.69 | 3 | 3 |
| Ultimaker2 (Ulticode) | 659 | 23019 | 1874 | 20.07/20.13/20.2 | 4.80 | 4 | 4 |
| Griffin | 652 | 23056 | 1875 | 20.07/20.13/20.14 | 4.72 | 4 | 3 |
| Repetier | 652 | 23042 | 1875 | 20.02/20.06/20.23 | 4.56 | 3 | 3 |
| Makerbot | 652 | 23043 | 1875 | 19.67/19.86/21.34 | 4.77 | 1 | 1 |
| Bits from Bytes | 1.014 | 76031 | 1870 | N/a | N/a | N/a | N/a |
| Mach3 | 652 | 23042 | 1875 | N/a | N/a | N/a | N/a |

## 4. CONCLUSIONS

Nowadays, Fused Filament Fabrication is one of the most commonly used 3D printing technologies. The open-source character of this technology accounts for this success. This allowed professionals and the user community to develop rapid hardware and software. The Cura slicing tool is a great example of an open-source software supporting more than 400 commercial printers and nine G-code flavours.

This study evaluated the influence of available G-code flavours in the Cura slicing software by using an XYZ calibration cube as a benchmark model. The resulting parts were evaluated using multiple criteria such as G-code file size, number of lines, printing time, weight, dimensional accuracy, and defects. The results showed that there is no significant difference in metadata generation. The registered differences in G-code size are based on flavours' algorithms' way of generating headers and footers. The best model quality can be obtained using Ulticode or Griffin flavours.

For average users, the best approach is to stick to the flavour recommended by the manufacturer of each 3D printer. However, for more experienced users, almost all flavours can be used because the resulting model quality can be improved by fine-tuning the settings of parameters unavailable in the default profile.

*Conflict of interests*

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

E.S.C. conceived, designed, performed experiments, analysed the results, wrote the manuscript S.A. and E.V. analysed the experiments, technical proof of results, and reviewed of the manuscript. All authors have read and agreed to the published version of the manuscript.

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