CAPÍTULO 4

PROTOTYPING IN ENGINEERING EDUCATION: DEVELOPMENT OF AN OPERATION MANUAL FOR 3D PRINTING

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ABSTRACT: Additive manufacturing, through Fused Deposition Modeling (FDM) technology, has stood out as both a pedagogical and technical tool in engineering education. This chapter presents the development and application of an operation manual for the Creality Ender 3 V2 3D printer, with a focus on the practical training of students and professionals. The adopted methodology involved 3D modeling in SolidWorks , slicing in Ultimaker Cura, and printing using PLA filament. Three replicas of a test part were produced, designed with multiple and complex geometries to assess dimensional accuracy and process repeatability. The comparative analysis between the CAD model and the printed parts demonstrated solid technical performance, confirming the applicability of the methodology in the academic context. The results highlight the potential of 3D printing as a supporting tool for developing technical skills in multidisciplinary learning environments.

KEYWORDS: 3D PRINTING; PROTOTYPING; ENGINEERING EDUCATION; INTERDISCIPLINARITY.

INTRODUCTION

Additive manufacturing, especially through Fused Deposition Modeling (FDM) technology, has become an essential tool in the prototyping stage of product development processes. Its ability to rapidly materialize virtual models into physical objects positively impacts the time, cost, and quality of projects across various fields of engineering (JENSEN, ÖZKIL, MORTENSEN, 2016).

The advancement of low-cost 3D printers, such as Creality Ender 3 V2, has enabled the democratization of rapid prototyping. These machines allow for direct experimentation by students, researchers, and professionals, enhancing autonomy in creative and iterative processes within academic and technical contexts (WANG, RANSCOMBE, EISENBART, 2024).

The versatility of 3D printing has expanded its use beyond mechanical engineering, reaching fields such as electrical, production, biomedical, and civil engineering. In these fields, the technology is employed in the creation of anatomical models, electronic devices, prototype structures, and replacement parts, among others. This broad applicability demonstrates the potential of additive manufacturing as a support tool for innovation and interdisciplinary development, fostering greater integration between theory and practice in academic and professional environments (EL KHATIB *et al*., 2019; GHAFFAR *et al.*, 2024; TÖRÖK, DUPLÁKOVÁ, 2025).

In addition to knowledge of virtual modeling and model slicing, operating a 3D printer requires technical mastery of its components, settings, and materials. Proper user training regarding equipment usage is essential to ensure the quality, safety, and efficiency of the outcomes (BASTAWROUS *et al.*, 2021).

Therefore, this chapter aims to present, based on a developed operation manual for the Creality Ender 3 V2 3D printer, practical and operational guidelines applicable to the broader context of engineering. The proposal is to establish connections between the use of the printer and the real demands of prototyping, contributing to the training of professionals better prepared to operate in environments of innovation and technological development.

METHODOLOGY

To obtain the aforementioned manual, software tools widely adopted in the context of prototyping were used, such as SolidWorks for three-dimensional modeling and Ultimaker Cura for slicing the models. The activities were carried out in a controlled environment, following best practices for preparation, calibration, and safe operation of the equipment.

The material selected for printing was polylactic acid (PLA), a thermoplastic widely used in educational and research settings due to its good machinability, ease of extrusion, dimensional stability, and sustainable properties such as biodegradability and environmental compatibility. These characteristics make PLA ideal for didactic applications and design validation tests (EL KHATIB *et al.*, 2019; TÜMER, ERBIL, 2021; MASZYBROCKA *et al*.,2022).

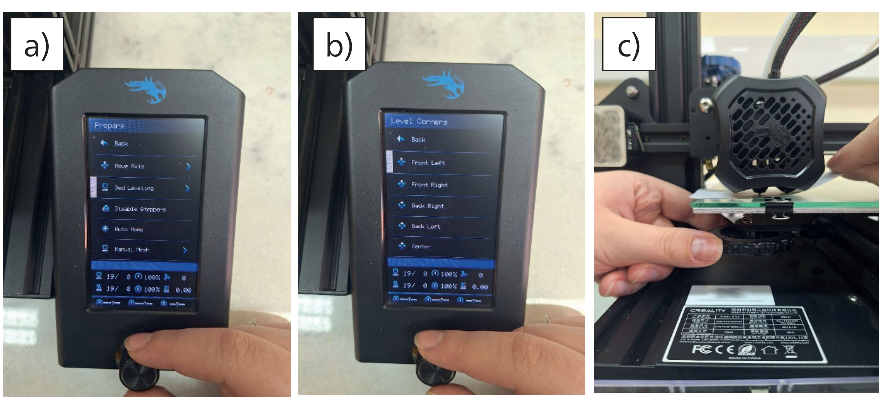
The methodology was structured into three main stages: equipment preparation, digital configuration of the model, and execution of the print followed by technical inspection of the obtained parts. All stages were documented with the aim of producing a replicable and multidisciplinary instructional material, in line with the practices of rapid prototyping in academic and professional contexts, as suggested in Bastawrous et al (2021).

Equipment Preparation

The printer was placed on a flat surface in an area protected from drafts and temperature fluctuations, minimizing warping during the printing process. Once these precautions were taken, the print bed was cleaned with a dry cloth to remove solid residues and improve the adhesion of the first layer to be printed.

Next, bed leveling was performed: a procedure considered critical to the success of the manufacturing process (JENSEN, ÖZKIL, MORTENSEN, 2016; RAJKUMAR, 2022). On the control panel, by turning the knob to select a function and clicking the button to confirm, the "Prepare" tab was accessed and the "Auto Home" function was used to align the axes and position the extruder nozzle at the origin point. Entering the "Bed Leveling" function and using a sheet of 75g/m^2 paper positioned between the nozzle and the bed, manual adjustments were made using the four leveling knobs in the four corners of the bed: "Front Left", "Front Right", "Back Left", and "Back Right" (Figure 1). The sheet should slide with slight resistance, indicating the ideal distance between the nozzle and the printing surface.

Figure 1 – Manual bed leveling adjustment: (a) Entering the "Bed Leveling"; (b) Setting the four corners of the bed; (c) Bed leveling performed by the knobs using a sheet of 75g/m^2 paper.

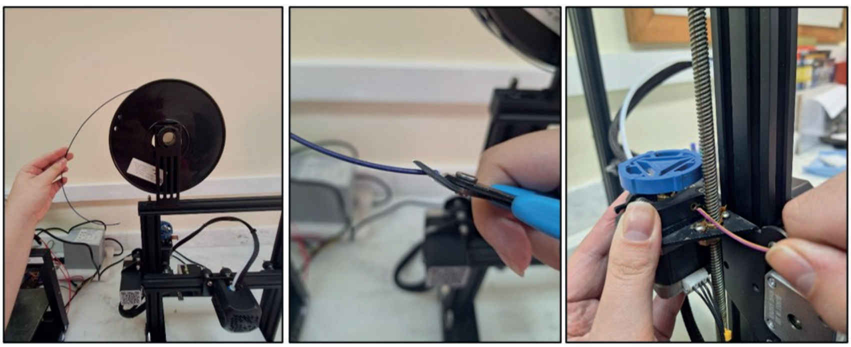


Source: Author's own work (2025).

Some other printer models have or allow the possibility of promoting leveling automatically.

After calibration, the PLA filament was installed. The spool was placed on the top holder with counterclockwise unwinding, and the tip of the filament was cut at a 45° angle and inserted into the extruder until it reached the “HotEnd” (Figure 2). This procedure ensured proper and continuous material feeding.

Figure 2 – Positioning and insertion of the PLA filament with the tip cut at a 45° angle.

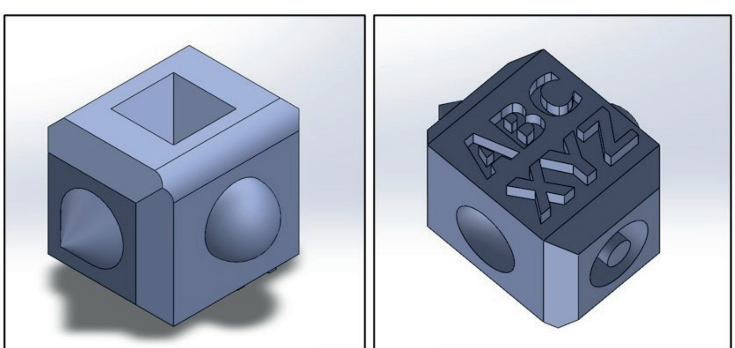


Source: Author’s own work (2025).

Modeling And Slicing Of The Part

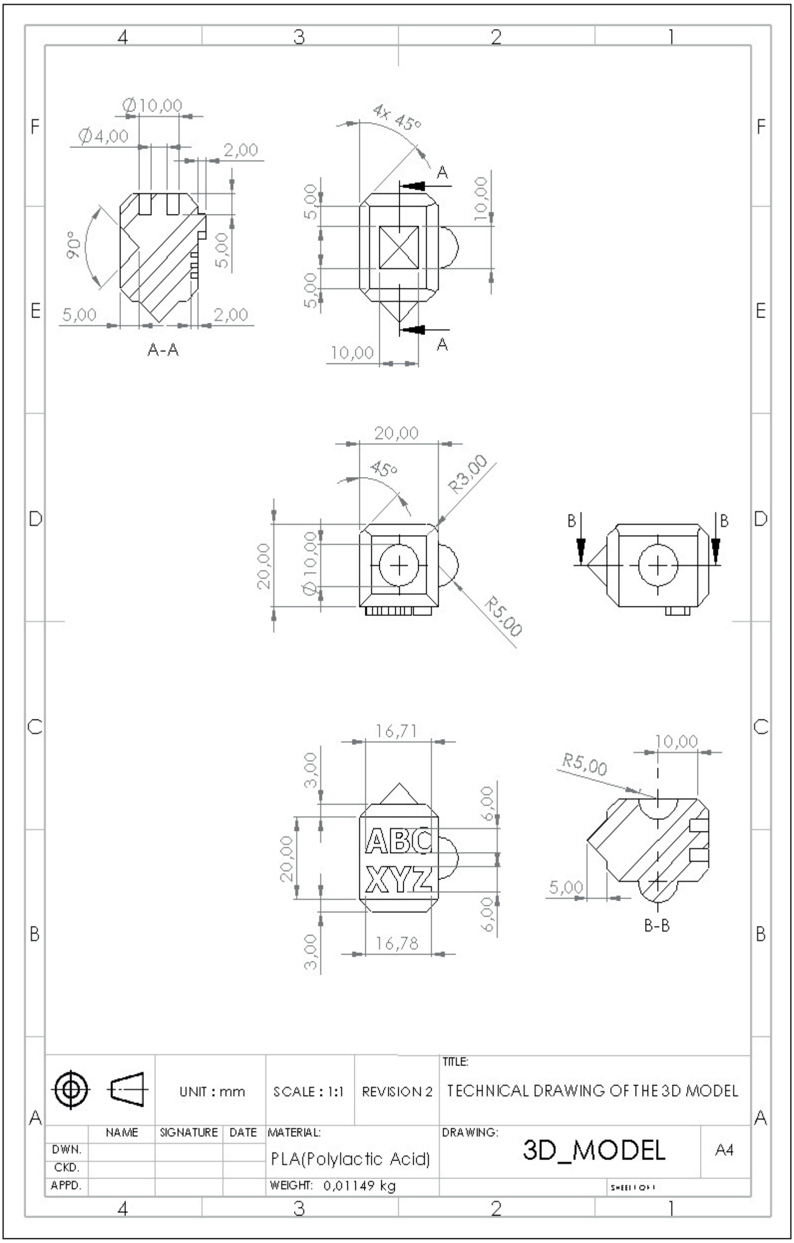
The three-dimensional modeling of the test part was carried out in SolidWorks, incorporating various intentional geometries such as 45° inclined angles, chamfers, fillets, spheres, protrusions, cavities, embossed and engraved texts, among others. The purpose of the part was to enable the analysis of the printer’s ability to accurately reproduce complex geometric details.

Figure 3 – 3D model developed in SolidWorks with multiple geometric features.



Source: Author’s own work (2025).

Figure 4 – Orthogonal views and technical dimensions of the test part.



Source: Author's own work (2025).

After completing the modeling, the file was exported in .STL format and imported into Ultimaker Cura. In the main interface of the software, at the "Prepare" tab, first select the printer model from the left panel of the top-center bar. Then define the filament type and nozzle diameter in the center panel. Finally insert the configuration parameters listed in Table 1 using the panel on the right. Support structures were enabled to ensure proper construction of overhanging regions, as identified by the slicing software.

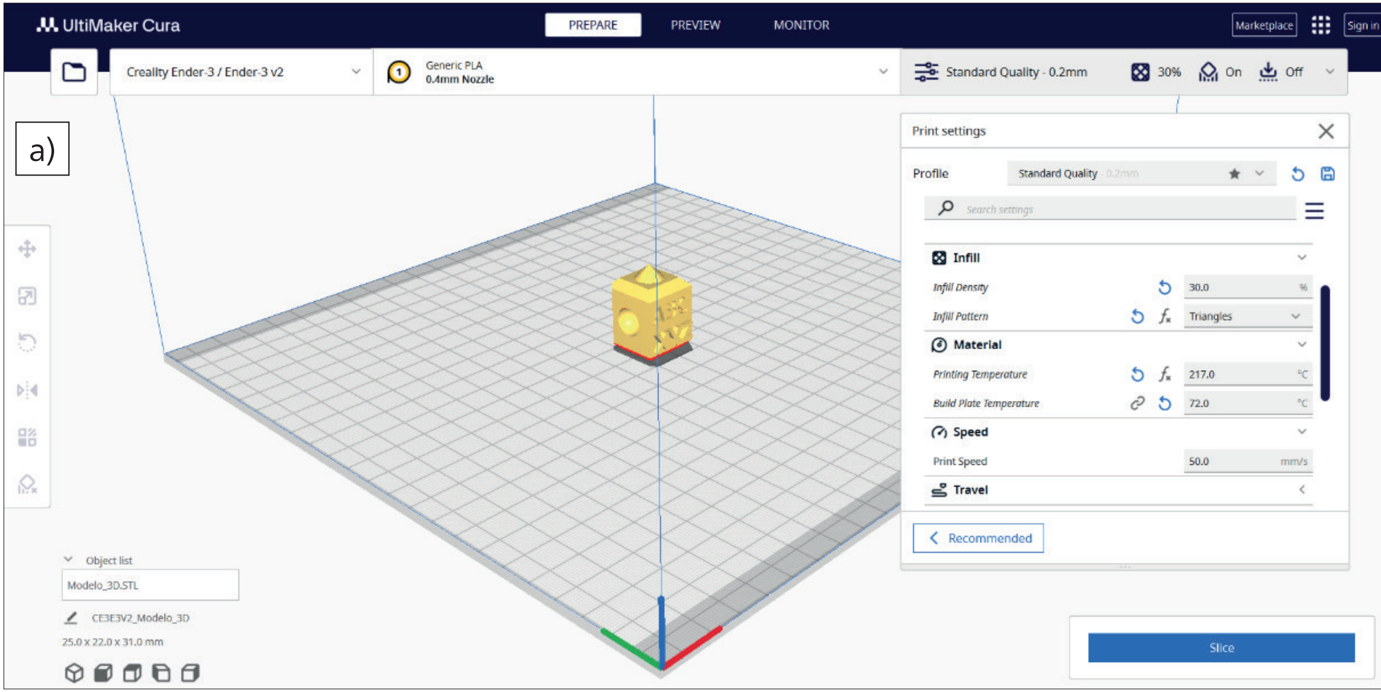
Table 1 – Configuration parameters.

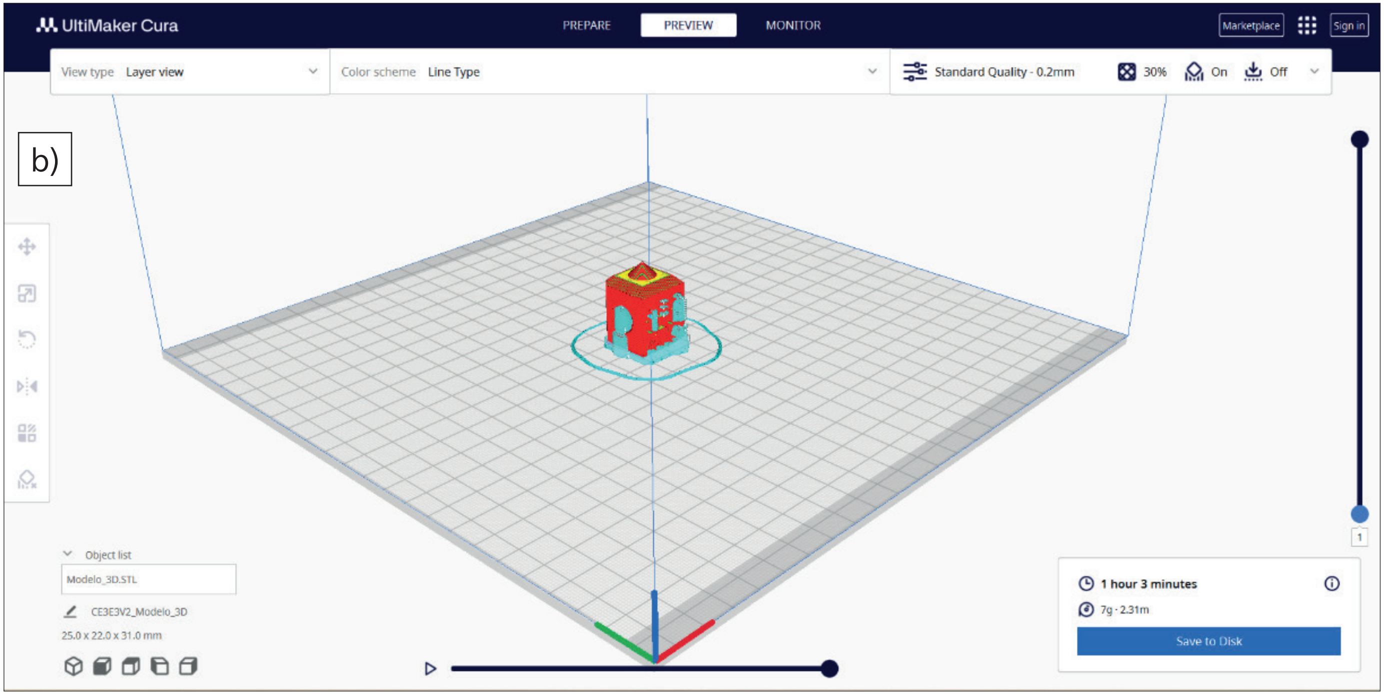
Layer Height	0.2 mm
Infill Density	30%
Infill Pattern	triangular
Print Speed	50 mm/s
Printing Temperature	217 °C
Build Plate Temperature	72 °C

The settings were defined according to the optimal values recommended by the printer manufacturer, while the printing temperatures (nozzle and bed) were based on the average values suggested by the PLA filament manufacturer and supported by recent studies on FDM performance (BASTAWROUS *et al.*, 2021; TÜMER, ERBIL, 2021).

With the settings properly adjusted, the model was sliced using the command located in the lower right corner of the interface (Figure 5-a) and then the Preview tab was accessed for visual inspection of the slicing, allowing verification of layer conformity and support distribution before sending it to print (Figure 5-b).

Figure 5 – Main interface of the software of the Ultimaker Cura: a) Print parameter configuration; b) Visual inspection of the slicing.





Source: Author's own work (2025).

After slicing, the model was automatically converted by the software into a G-code file, a format recognized by the 3D printer and responsible for gathering machine instructions regarding axis displacements, deposition speeds, temperatures, and extrusion parameters. The file was then saved to a microSD card and transferred to the printer, enabling the start of additive manufacturing of the part.

Print Execution And Finishing

After transferring the G-code file to the printer, the printing process was initiated directly from the printer's control panel, by selecting the "Print" option (Figure 6-a) and then confirming the "CE3E3V2_Modelo_3D_cubo.gcode" file (Figure 6-b). First, the machine automatically heats the bed and then the extruder nozzle. Finally, the axis homing procedure (axes referencing) is executed, initiating the part production.

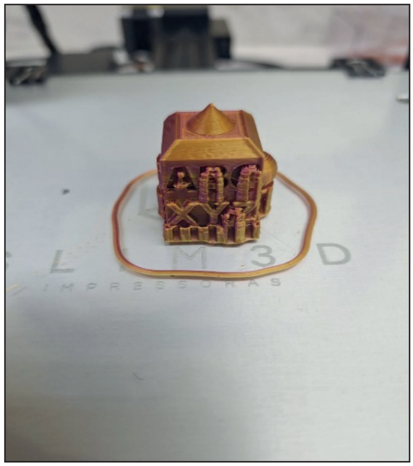
Figure 6 – Initiating the print from the control panel.

Source: Author's own work (2025).

The first layers were carefully monitored to ensure proper extrusion and adhesion. During operation, the stability of the bed, continuous filament flow, and the integrity of the layers formation were observed. The entire process took approximately 70 minutes.

At the end of the print, the part was removed using a spatula, and the support structures were carefully extracted with precision tweezers. The print bed was cleaned again to prevent residue buildup and ensure optimal conditions for future prints.

Figure 7 – Finished part before removal and support extraction.



Source: Author's own work (2025).

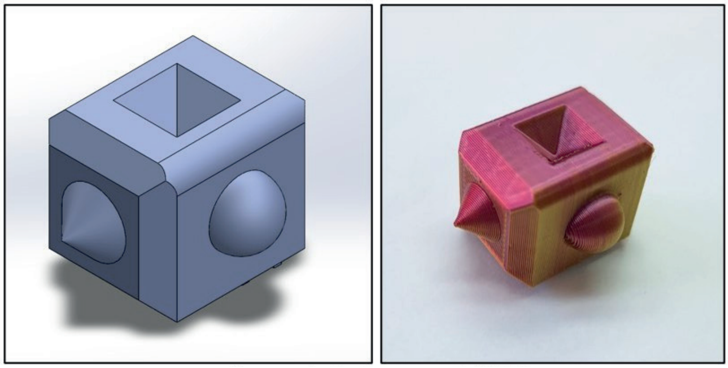
Three replicas of the part were produced to validate the repeatability and quality of the process. The technical analysis included a visual inspection of the surface finish, verification of the sharpness of the features, and measurements using a digital caliper to compare with the CAD model in order to assess dimensional deviations and the printer's technical performance (EL KHATIB *et al*., 2019).

RESULTS AND DISCUSSION

The execution of the prototyping process allowed for the evaluation of the dimensional accuracy and visual quality of the part produced through additive manufacturing, based on the originally developed CAD model. The 3D model, created in SolidWorks, served as a reference for both visual and metrological inspection of the PLA-printed part.

The isometric views comparison (Figure 8) revealed a high degree of similarity between the digital design and the physical object. Features such as embossments, cavities, chamfers, and fillets were reproduced with good definition, maintaining the geometry and proportions specified in the project. Layer adhesion and continuous extrusion were positively observed, with no visible defects or interruptions during the printing process.

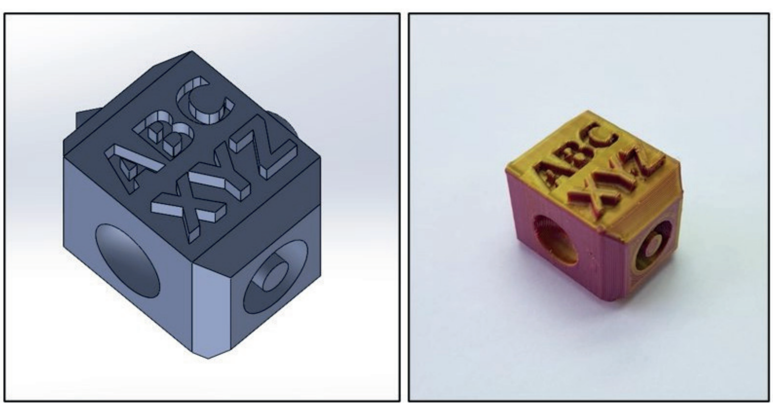
Figure 8 – Comparison between the CAD model and the printed part with isometric view.



Source: Author's own work (2025).

With the rotation of the isometric views (Figure 9), it can be observed the remaining faces of the part, allowing the analysis of inclined surfaces, reliefs, and inscriptions. The comparison revealed good definition even in hard-to-reach areas, with minor imperfections on the edges of some fine details, attributed to the resolution limitations of the FDM process and the material properties of PLA (EL KHATIB *et al*., 2019; TÜMER, ERBIL, 2021).

Figure 9 – Comparison between the CAD model and the printed part with rotated isometric view.



Source: Author's own work (2025).

Despite these minor inaccuracies, the obtained results were satisfactory for academic and experimental purposes. The part demonstrated good dimensional stability, with deviations within the acceptable range for initial validation projects. The three replicas produced showed consistency among themselves, highlighting the repeatability of the process.

CONCLUSION

The experience described in this chapter demonstrated the feasibility and relevance of using the Creality Ender 3 V2 3D printer as a support tool for prototyping in multiple fields of engineering. The development and application of an operational manual not only standardized the printing process but also enabled the practical training of students and professionals, promoting greater familiarity with the fundamentals of additive manufacturing.

The choice of PLA filament proved to be suitable for educational and experimental contexts, yielding satisfactory results in terms of dimensional stability, surface finish, and geometric fidelity. The comparative analysis between the digital model and the printed parts highlighted the precision of the FDM system in replicating complex geometries, even when considering the inherent limitations of the technology and material used.

Furthermore, the consistent reproduction of three replicas validated the repeatability of the process and reinforced the potential of 3D printing as an accessible and effective tool for concept testing, dimensional verification, and technical training. The adopted methodology, combining modeling, slicing, operation, and analysis, can be replicated in various academic contexts, encouraging the integration of theory and practice in engineering education.

In this sense, additive manufacturing prototyping is established as a strategic pedagogical and technical resource, especially when combined with well-structured and documented practices, such as the manual developed in this work.

STATEMENT OF RESPONSIBILITY

The authors declare that they are the only ones responsible for the content presented in this chapter, ensuring the accuracy of the information, the originality of the work, and compliance with current ethical and academic standards. All sources used have been properly cited, and there is no conflict of interest related to this publication.

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