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REVIEW

Free software and the 3D printing revolution: educational and practical implications

El software libre y la revolución de la impresión 3D: implicaciones educativas y prácticas

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ABSTRACT

Additive manufacturing has experienced exponential growth in the last decade, going from being a laboratory curiosity to becoming a dominant industrial and household technology. Among the different currents that have driven this development, the Reprap (Replicator + 3D Printer) movement stands out for its philosophy of "printing everything you can print", based on open hardware, low cost and self-replication. Since its inception in the mid-2000s, Reprap has sown the seeds of a community where collaboration and the exchange of designs are as essential as the print itself.

Keywords: Additive manufacturing; Reprap; 3D printing; Open hardware.

RESUMEN

La fabricación aditiva ha experimentado un crecimiento exponencial en la última década, pasando de ser una curiosidad de laboratorio a convertirse en una tecnología industrial y doméstica dominante. Entre las distintas corrientes que han impulsado este desarrollo, el movimiento Reprap (Replicator + 3-D Printer) destaca por su filosofía de "imprimir todo lo que puedas imprimir", basada en hardware abierto, bajo costo y auto-replicación. Desde sus inicios a mediados de los años 2000, Reprap ha sembrado las semillas de una comunidad donde la colaboración y el intercambio de diseños son tan esenciales como la propia impresión.

Palabras clave: Fabricación aditiva; Reprap; Impresión 3D; Hardware abierto.

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INTRODUCTION

3D printing has revolutionized manufacturing by making it possible to create three-dimensional parts layer by layer. Open-source initiatives such as the RepRap project (2005) have made this technology more accessible and affordable. RepRap proposed a self-replicating 3D printer (capable of printing many of its own parts), with designs published under a free license. This philosophy of open hardware and software means that "blueprints, designs, and software are free for everyone. Anyone can build a RepRap printer if they have access to the materials and instructions." As a result, instead of relying on closed vendors, the community can customize and evolve printers, introducing variants and constant improvements. In fact, the literature highlights that a basic RepRap printer cost about $500, much lower than initial commercial models, and that its innovation rate "accelerates much faster" than in proprietary printers. On the other hand, the development of online platforms (such as Thingiverse) allows 3D designs to be shared freely, expanding the democratization of additive manufacturing and access to digital educational resources.

Currently, China dominates the mass production of 3-D printers with brands such as Bambulab, Creality, Anycubic, or Snapmaker. However, in the open-source realm, pioneers who have managed to combine the accessibility of open hardware with competitive performance continue to shine: Prusa Research, Sovol, and the Voron family. Each of these manufacturers brings a distinct vision, from industrial manufacturing (Prusa) to high-precision modular construction (Sovol, Voron), and all maintain the Reprap heritage in their designs, documentation, and communities.

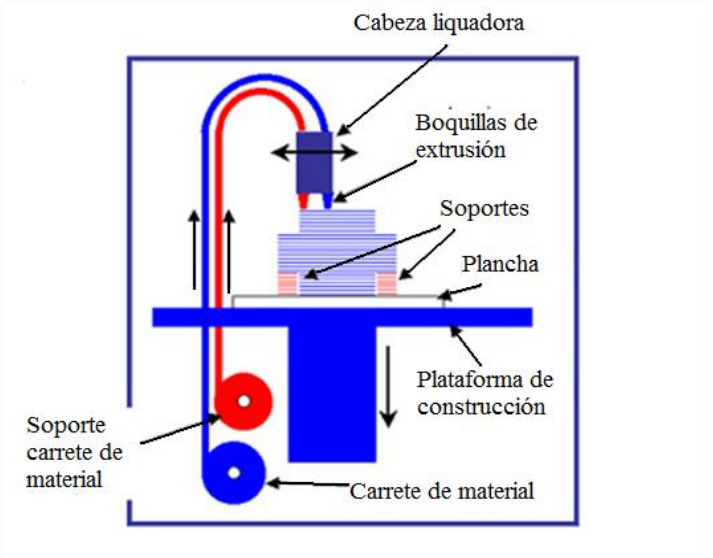
Additive manufacturing

Additive manufacturing has multiple applications, including personalized medical and dental parts, architecture and art, education and research, and aeronautics and the automotive industry. It enables faster prototype development, the production of highly complex parts in a lighter, more cost-effective, and personalized manner, and the manufacture of low-volume spare parts in less time. Innovation is evident in each of these areas.

To create parts, different technologies, techniques and materials are used, in the case of plastic the technology applied is fused deposition modeling or FDM, which consists of the deposition layer by layer of molten polymeric material, one on top of the other, until the designed part is completed [1], generally a coil containing a polymeric filament is used that melts second by second once it has passed through an extruder at the moment it reaches the melting point [2] (see figure 1). The materials used withstand thirst temperatures from 80°C to 225 °C.

The advantages of FDM manufacturing include the production of prototypes that are non-deforming, lightweight, large, functional during laboratory tests, suitable for polishing, painting, or chroming, and low-cost. However, its disadvantages include a granular appearance, accuracy restricted by the filament size, slightly longer generation times for large parts, and potential distortion from heating and rapid cooling.

Figure 1. Operating principle of the FDM machine.



Source: Laboratory of Information Processing Science, University of Helsinki. http://www.cs.hut.fihttp://www.cs.hut.fi

For the case of manufacturing parts with liquid resin, UV light is used to solidify the photosensitive resin; the technology used is stereolithography or STL (see figure 2), which is a rapid prototyping system with which, through the processing of data obtained through helical computed tomography of the patients and by means of a computer system, solid three-dimensional models or prototypes are obtained [6]. When the image is captured, a Digital Imaging and Communications in Medicine or DICOM format is used; its processing is carried out in specialized software for images or MIMICS, so that the stereolithography apparatus creates the model with 99% fidelity. [7]

Figure 2. Stereolithography3D Systems SLA 750®

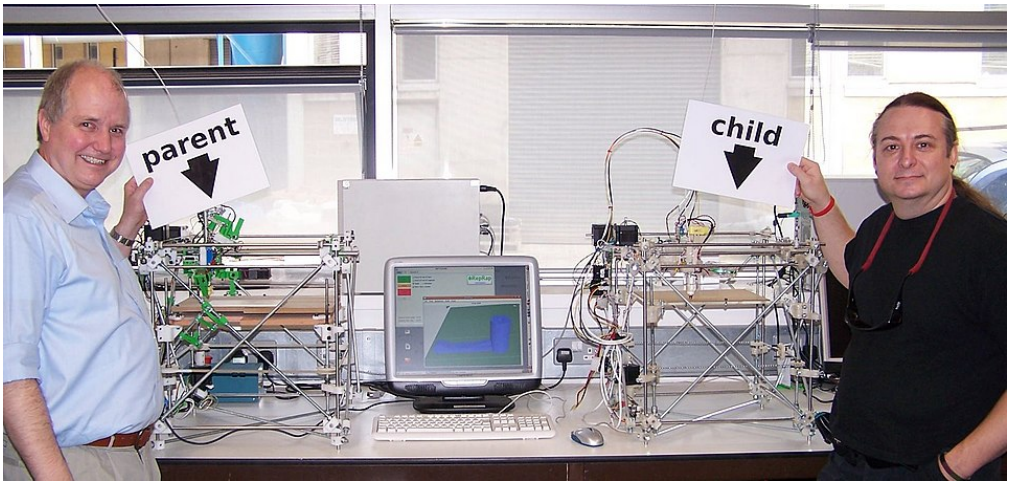
Source: https://es.3dsystems.com/3d-printers/sla-750https://es.3dsystems.com/3d-printers/sla-750

The Reprap philosophy in the context of additive manufacturing

RepRap was founded in 2005 by Adrian Bowyer, created as an open-source project that seeks to build 3D printers that can reproduce (replicate) almost all their parts, thus reducing dependence on external suppliers.

"Due to the ability of these machines to manufacture some of their own parts, the authors foresaw the possibility of low-cost RepRap units, enabling the manufacture of complex products without the need for extensive industrial infrastructure."

Figure 3. Adrian Bowyer (left) and Vik Olliver (right) with a parent RepRap machine, made on a conventional rapid prototyping machine, and the first complete working child RepRap machine, made by RepRap on the left.



Source: https://en.wikipedia.org/wiki/File:First_replication.jpghttps://en.wikipedia.org/wiki/File:First_replication.jpg

The infant machine manufactured its first successful grandchild piece at 14:00 UTC on 29 May 2008 at the University of Bath in the United Kingdom, a few minutes after its assembly.

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The three pillars of Reprap

Prusa Research

- Founding (2012) by Josef Prusa in the Czech Republic; origin of the Prusa MK2 inspired by the Reprap-Original.
- Business model: do-it-yourself kits and complete printers with global technical support.

Key innovations:

- Z-axis linear system with high-precision lead screw.
- Modified E3D V6 hot-end (Prusa i3 MK2) that allows printing of flexible and high-performance filaments. Today it is used for a multitude of RepRap-based printers.
- Firmware “Prusa-Firmware” derived from Marlin, optimized for retraction, thermal runaway protection, and automatic calibration.

Contributions to Reprap and the community

Printables: online platform that specializes in the distribution of downloadable files for 3D printing, where users can find models and designs to print.

PrusaSlicer: open-source software developed to generate G-code files for 3D printers; it offers compatibility with FDM and SLA printers.

Firmware and printable parts of Prusa 3D printers: “Our mission is clear: make pleasant machines for everyone to use. Open source is our heart, sharing how we do things so others can learn and create.”

Sovol

• Foundation (2015) in China; it positions itself as a bridge between mass production and the open-source community.

- Business model: direct sale of complete printers with limited warranty, but with open access to CAD designs and firmware.
- Key innovations:
  - CoreXY structure that reduces the weight of the X/Y axis and improves speed.
  - Hot-end ‘Sovol’ based on E3D V6 with aluminum layer for improved thermal dissipation.
  - Firmware “Marlin-Sovol” includes modules for automatic extruder calibration (auto-tuning) and support for reversible filament.

Contributions to Reprap and the community

SV06: based on the Prusa i3 MK2, it is a good option for users looking for a printer similar to Prusa’s while preserving the open source from which it was born.

Voron

- Founded (2015) as an open-source community project; versions 0.x, 1.0 and the recent Voron 2.4.
- Business model: GitHub repository with free 3-D plans; the community manufactures parts in local workshops or through printing services.

Key innovations:

- CoreXY platform with steel frame structure and linear rail axes, ensuring high rigidity.
- Hot-end “Voron” (Hot-End V6) with reinforced aluminum layer and improved ventilation.
- Firmware “Marlin-Voron” with support for auto-leveling, multi-extruder, and steps per mm calibration.

Contributions:

Its plans and steel frame were used in the first Bambulab P1 printer (Bambulab currently

does not attribute Voron's contribution in its first printers).

Access to the original RepRap experience, updated by the community, giving the possibility to customize printers according to the user's needs and capabilities.

Plans and steel frame were used in the Sovol Zero and Sovol SV08 printers, adapting the project for a mass production system and giving due attribution to the Voron project.

Figures 4 and 5. Sovol SV06(left). Prusa MK2S(right)

Source: figure 4. https://www.sovol3d.com/products/sovol-sv06-best-budget-3d-printer-for-beginner Figure 5. https://www.prusa3d.com/page/open-source-at-prusa-research_236812/?_gl=1*cfnji0*_gcl_au*NTQ3MDI0NDg3LjE3NjE4NjY1ODQ.*_ga*OTE2NTMwNjQ4LjE3NjE4NjY1ODQ.*_ga_3HK7B7RT5V*czE3NjE4NjY1ODQkbzEkZzEkdDE3NjE4NjY2MDYkajM4JGwwJGgwhttps://www.sovol3d.com/products/sovol-sv06-best-budget-3d-printer-for-beginnerhttps://www.prusa3d.com/page/open-source-at-prusa-research_236812/?_gl=1*cfnji0*_gcl_au*NTQ3MDI0NDg3LjE3NjE4NjY1ODQ.*_ga*OTE2NTMwNjQ4LjE3NjE4NjY1ODQ.*_ga_3HK7B7RT5V*czE3NjE4NjY1ODQkbzEkZzEkdDE3NjE4NjY2MDYkajM4JGwwJGgw

Figure 6. Voron 2.4 Pro

Source: https://www.hotend.eu/p/voron-24-pro-kit-350mm

Free tools for 3D printing

The institutions have various specific open applications for 3D design and printing. Among the most notable are:

FreeCAD: an open-source parametric CAD modeler. It is mainly oriented towards mechanical engineering, but "it also adapts to fields such as architecture, product design, and 3D printing". It allows generating 3D solids with parametric constraints, facilitating iterative design changes without having to redo everything.

Blender is a free and open-source 3D creation suite. Although it was conceived for animation and graphics, its powerful 3D modeling and sculpting tools make it useful for designing complex models that are later converted into printable files (STL). Being cross-platform and supported by a large community, Blender is widely used in academic and creative environments.

Cura (Ultimaker Cura) is an open-source slicer widely used to prepare 3D models for printing. Cura loads STL or OBJ files and generates the machine file (G-code) that guides the printer. It is popular for its user-friendly interface, hundreds of preconfigured profiles, and advanced customization capabilities to adjust speed, quality, and supports.

PrusaSlicer is a free slicer created by Prusa Research. Like Cura, it converts 3D models into printing instructions. It is "feature-rich and frequently updated," offering simple or advanced printing modes. PrusaSlicer includes a multitude of profiles for Prusa and third-party printers, optimizing results without license cost.

OctoPrint is a web platform for remote control of 3D printers. It is 100% free software (AGPL license). It runs on a Raspberry Pi or similar and allows managing printing jobs from a browser, monitoring the integrated camera, and being extended through community plugins. OctoPrint exemplifies the "free software ecosystem" around 3D printing, integrating open hardware and software.

Other tools include programs such as OpenSCAD (scripting-based CAD) or Slic3r (original GPL slicer), which are also useful free alternatives. Most of these applications can export standard formats (STL, OBJ, etc.) compatible with printers from different manufacturers.

Educational applications in the university

3D printing with free software is used in multiple university degree programs:

Engineering: Engineering students use 3D printers to manufacture functional prototypes (mechanical parts, electronic components, drones, electric vehicles, etc.). For example, at the University of Calgary, students print windmill prototypes and electronic enclosures weekly as part of their courses. Free CAD tools such as FreeCAD are incorporated into mechanical design teaching because they allow modeling complex assemblies and generating technical drawings.

Design and Architecture: Industrial design and architecture programs employ free software to create 3D models of products, furniture, and scale models. With tools such as Blender or FreeCAD, future architects can conceive advanced geometries that they subsequently produce as physical scale models. Likewise, they print scale models of structures or construction modules to validate spatial concepts. These applications foster creativity in design and the material representation of ideas.

Biomedicine and Health: 3D printing in medicine enables the production of anatomical models, prostheses, and custom-made artificial organs. For example, academic projects print synthetic hearts or bones to plan surgeries. One documented case is that of the Fundación Markoptic (Mexico), which uses open-source 3D printers to manufacture prostheses donated to people with limited resources. In this way, open-source technology contributes to affordable, patient-adapted healthcare solutions.

Other STEM areas and art: Biology students can print models of molecules or fossils, and chemistry students can print labware prototypes. In art and special education, reproductions of artworks have been printed for people with visual disabilities (for example, the Museo del Prado printed relief sculptures). 3D printing is even explored in fashion and jewelry, where students experiment with rigid textiles or ornamental pieces using open-source tools.

University Case Studies

Various universities have documented their experience with 3D printing in real environments:

ZHAW (Switzerland): At the Zurich University of Applied Sciences, engineering students designed a 3D-printed extruder with a fourth axis, solving the challenge of generating 90° overhangs without supports. The team openly shared the design on 3D printing networks. According to their reports, this open approach "democratizes access to technology and allows other institutions to

learn from and take advantage of this pioneering work." Retrieved from: https://blog.prusa3d.com/the-power-of-3d-printing-open-source-in-education-a-revolutionary-leap-at-zhaw_78623/

University of Calgary (Canada): The Schulich School of Engineering opened a makerspace with more than 70 Prusa 3D printers available to any student. An online procedure is sufficient to access the printing queue. The result was a collaborative environment where experienced students train novices in slicing techniques, material selection, and printer maintenance. Their projects include prototypes of wind turbines, electronic enclosures, and even T-Rex-shaped guitars, reinforcing technical skills and teamwork. Those responsible conclude that this generous access to 3D printing prepares graduates with practical experience valuable to industry. Retrieved from: https://blog.prusa3d.com/es/como-el-makerspace-de-la-ucalgary-da-vida-a-las-ideas_114582/

UNIFEBE (Brazil): A notable case is that of UNIFEBE University, which created a small innovation center with two 3D printers. With this equipment, they changed "completely their engineering programs, focusing them on additive manufacturing and Manufacturing 4.0." By using this technology in the curriculum, they moved from one-way teaching to a dynamic where students and professors collaborate to solve real projects. This model illustrates how 3D printing can reorient engineering education toward practical and updated projects. Retrieved from: https://observatorio.tec.mx/edu-bits-blog/impresion-3d-como-herramienta-para-la-educacion/

ULPGC MakerSpace Library (Spain): The Universidad de Las Palmas de Gran Canaria incorporated a MakerSpace in its central library, equipped with a 3D printer, 3D scanner, laser cutter, etc. Its page describes this space as a place to "create knowledge... experiment and learn by doing". The objectives include "fostering collaborative and interdisciplinary work". This approach reflects the university's maker culture: students from different programs share a common workshop to develop joint projects, apply 3D technology in their studies, and embrace error as part of the creative process. Retrieved from: https://biblioteca.ulpgc.es/servicios/reprografia-impresion-3d

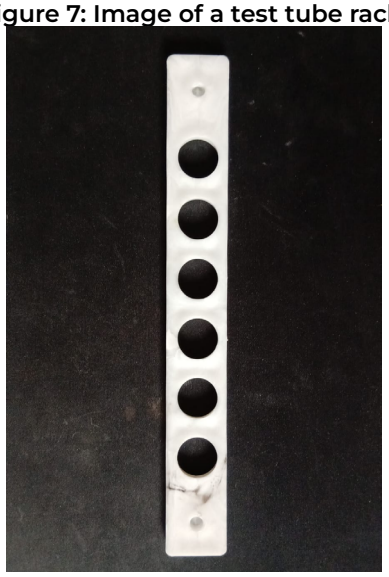
Emergence of 'open source' artificial intelligence as a support tool in the design of CAD and decorative models

With the arrival of generative artificial intelligence models for the general public and the release of Meta's Llama artificial intelligence as an open-source model, many companies began to provide "open-source" generative artificial intelligence tools; in our field, Tencent's Hunyuan3D-2 is an excellent tool for generating 3D files locally.

Next, an application of the Hunyuan3D-2 model as a support tool in the design of 3D models is presented.

Hunyuan3D-2 is an open-source 3D asset generation tool developed by Tencent. It allows the creation of high-quality 3D models from text descriptions, images, or sketches, using a process that combines geometry generation and texture synthesis.

Figure 7: Image of a test tube rack.

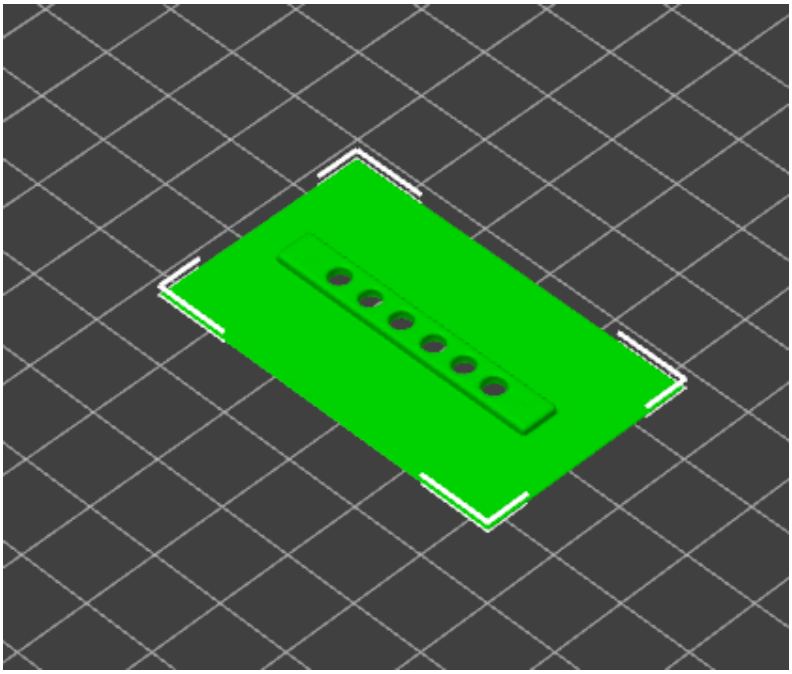


Source: own work.

Application of artificial intelligence as a support tool in the design of 3D models

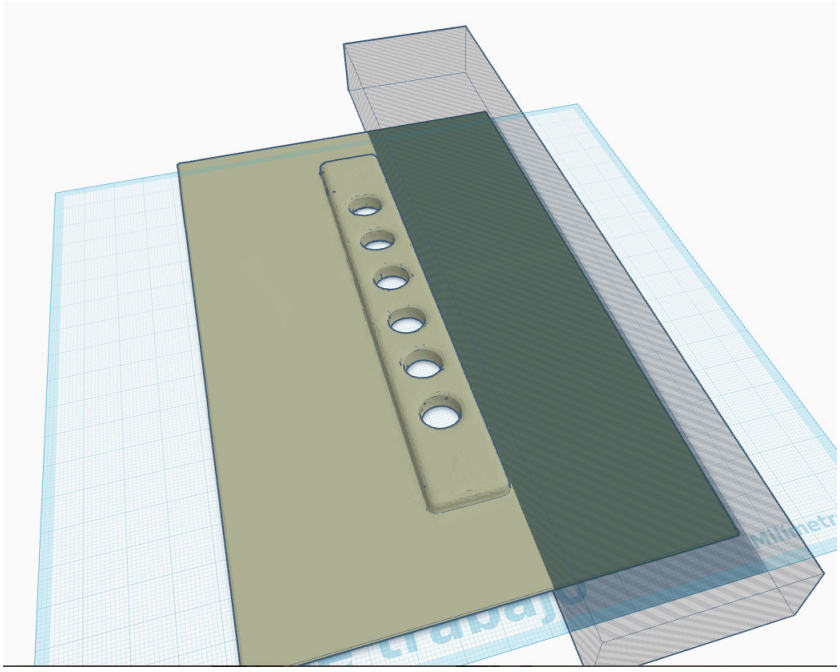
Before starting, running the model locally in its full size requires at least 24GB of RAM and 6GB of VRAM. In this case, the aim was to print a replacement part for a test tube rack; see Figure 7. Contrast between the piece and the background is necessary, and the best results are obtained with .PNG files.

Figure 8: Results obtained using the Hunyuan3D-2 model with Figure 7 as the original image.



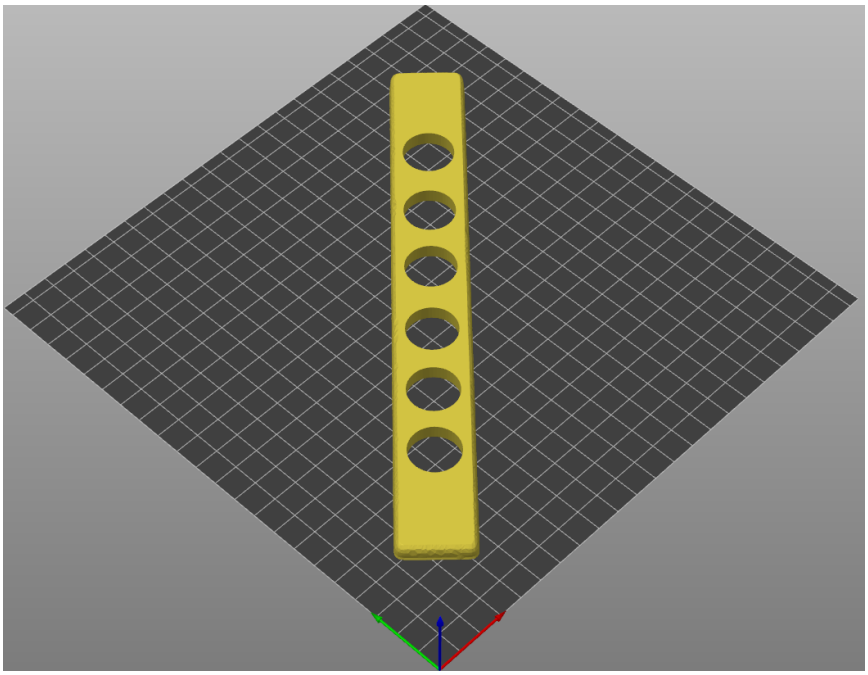
Source: own work.

Figure 9: Manual modification of Figure 8 in Tinkercad to obtain the result of Figure 7.



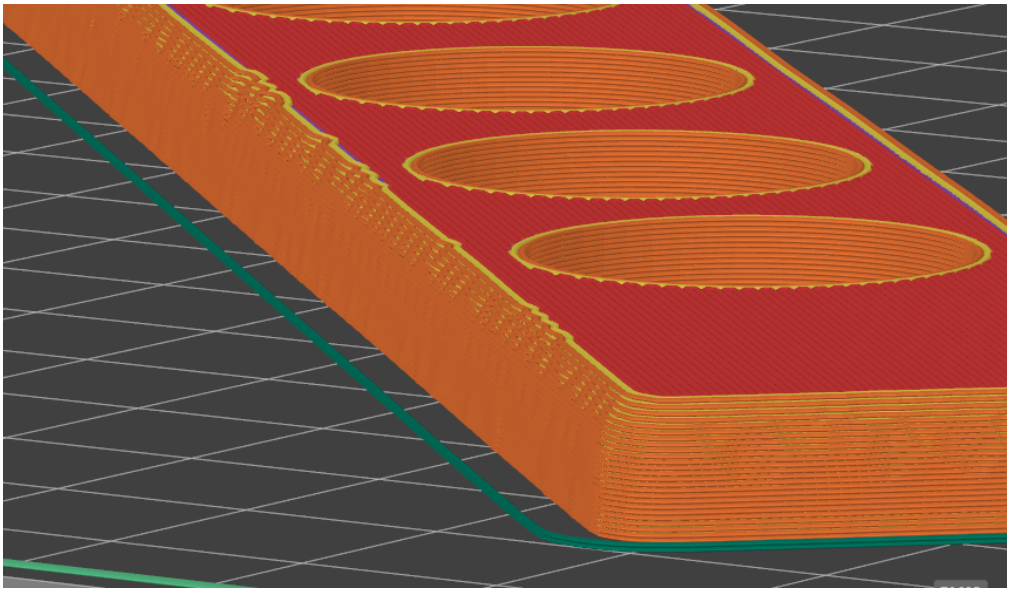
Source: own work.

Figure 10: Final result of the piece adapted to the dimensions of Figure 7. Only manual work was devoted to adapting the piece to the real dimensions; the generated Hunyuan3D-2 model was used as the basis for the model.



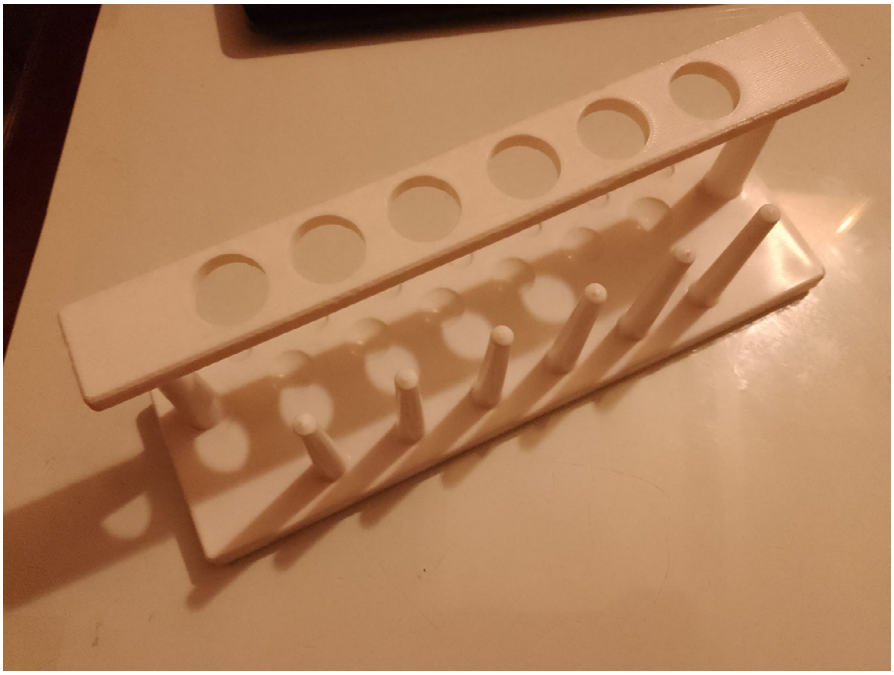
Source: own work.

Figure 11: Lamination of the modified part at a 0.24 layer height.



Source: own work.

Figure 12: Final result of the part. Printing time: 1 hour and 45 min (Elegoo Neptune 3 Pro). Design time: 1 hour and 30 min. Model generation time: 900 sec.



Source: own work.

It must be remembered that artificial intelligence is not a means to replace humans, but rather a tool to facilitate work and provide assistance to users who lack the skills or need a foundation to start working.

Conclusions

The RepRap project, conceived in 2005 by Adrian Bowyer, constitutes the historical starting point that has enabled the proliferation of autonomous and affordable 3-D printers. Its philosophy of "print everything you can print" translates into a value chain in which plans, designs, and firmware are released under open licenses (MIT, GPL, CC-BY). This openness not only reduces the initial acquisition cost (≈ USD 500 for a basic kit) but also fosters continuous innovation: users can modify, improve, and share their own adjustments, which has given rise to sub-projects such as Prusa Research, Sovol, and Voron. The self-replication capability and the availability of technical documentation have turned RepRap into a globally replicable model, with active communities driving improvements in both hardware (precise linear axes, optimized hot-ends) and software (firmware such as Marlin-Voron and Prusa-Firmware).

While China dominates the market with commercial brands (Creality, Anycubic, Snapmaker), open-source initiatives maintain qualitative leadership in terms of flexibility and customization. Companies such as Prusa Research offer do-it-yourself kits and complete printers with global technical support, integrating innovations such as the modified E3D V6 for flexible filaments and automatic calibration systems. Sovol combines a lightweight CoreXY structure with Marlin-Sovol firmware that allows extruder auto-tuning and support for reversible filaments. Voron, for its part, stands out for a robust steel frame, reinforced V6 hot-end, and Marlin-Voron firmware that facilitates auto-leveling and multi-extrusion. The synergy among these manufacturers demonstrates how the open-source philosophy can coexist with sustainable business models, offering products competitive in performance and price.

The open-source software ecosystem for 3-D printing includes FreeCAD (parametric modeling), Blender (organic modeling and sculpting), Cura and PrusaSlicer (slicers), and OctoPrint (remote control). These applications allow users to generate STL/OBJ files compatible with any printer, without license barriers. Furthermore, the availability of these resources facilitates the incorporation of 3-D printing into curricular plans in Engineering, Architecture, Biomedicine, and other STEM areas, contributing to active and project-based learning.

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