Sustainability of the 3D Printing Laboratory Operation on Faculty of Management Science and Informatics University of Žilina

Lukáš Čechovič, Marek Tebeľák, Michal Kubaščík, Juraj Miček

Abstract—“This paper focuses on the integration of sustainability into the educational process through the subject of 3D printing. Over recent years, 3D printers have become accessible to a broad public due to their affordability, user-friendliness, and reliability. In 2019, we introduced 3D printing as a subject at the Faculty of Management Science and Informatics University of Žilina with the goal of making it accessible to all students, regardless of their field of study. This multidisciplinary technology allows students to unleash their creativity and broaden their perspectives. The 3D printing process captivates students as they transform their ideas into tangible objects. Starting with a concept, they use CAD software for modeling and finalize their creations with a physical product—all within a single lesson. This hands-on approach has made the subject highly popular, leading to increased student participation and engagement. This paper emphasizes the importance of integrating sustainable practices into the 3D printing curriculum. Specifically, it explores strategies for recycling and reusing materials used during practical lessons to minimize waste and reduce the environmental impact. By promoting a circular approach to material usage, the subject aims to instill an awareness of sustainability in students. The paper also discusses the process of selecting appropriate technical equipment for the laboratory to support effective recycling of materials used in 3D printing. Ensuring student safety and the reliability of the equipment remains a priority, but the emphasis is placed on integrating tools and devices that enable the collection, processing, and reuse of waste materials, such as failed prints or support structures. This paper recommends that 3D printing, combined with sustainable practices, should become a fundamental component of education across various disciplines and institutions. [3]

Keywords— 3D printing, filament, sustainability, laboratory

I. INTRODUCTION

Through the process of learning how to design your own models and print them, you may encounter difficulties, which can result in plastic scraps such as support materials and failed prints. For years, it has been common practice to throw this scrap away, but as the issue of microplastics and plastic waste pollution becomes more relevant. As plastic materials degrade, they break into smaller pieces and are harder to eliminate. It has been proven that microplastics are even present in our bloodstreams and may cause many unwanted and harmful effects on the immune system and body.

In 2019, the Faculty of Management Science and Informatics in University of Žilina introduced 3D printing as a course with the goal of making it accessible to all students, regardless of their field of study. This multidisciplinary technology allows students to unleash their creativity and broaden their perspectives. Although it is good to teach people new things, their learning process may be slow úand riddled with mistakes that create plastic products no longer usable under normal circumstances unless recycled.

Since the 3D printing subject began operating, we have been collecting plastic waste from 3D printers with the intention of recycling it to produce our own filament. To further this goal, we are considering the purchase of a recycler. Additionally, we are working on developing our own version of the recycler in collaboration with students.

Recycling is one way to introduce sustainability into the learning and practices of students and 3D printing enthusiasts. It has many benefits, not only for nature, but also for finances and

Lukáš Čechovič, University of Zilina, Zilina, Slovakia (e-mail: lukas.cechovic@fri.uniza.sk)
Marek Tebeľák, University of Žilina, Slovak Republic (e-mail: tebelak2@stud.uniza.sk)
Michal Kubaščík, University of Žilina, Slovak Republic (e-mail: michal.kubascik@fri.uniza.sk)
Juraj Miček, University of Žilina, Slovak Republic (e-mail: juraj.micek@fri.uniza.sk)

overall self-sufficiency in this field. Unfortunately, due to the laws of nature, there is no way to achieve 100% self-sufficiency or 100% recycling of waste. However, through trial and error and working together, people have managed to create many thriving communities that collect waste plastic and repurpose it for new uses.

In the course on 3D printing in 2024, 255 grams of filament were used per student group. There were 138 groups in 2024, which amounts to a total consumption of 35,3175 kilograms of filament for the entire semester.

II. Proposed technical equipment

For the purposes of analysis in this article, we will use two different models of filament recyclers: Felfil and Filabot.

A. *Filabot EX2* [2]

- Build Quality: The Filabot EX2 has a robust, all-metal frame
- Temperature Range: It can reach up to 329°C, allowing it to handle a variety of materials including PLA, ABS, PETG, HIPS
- Extrusion Speed: The EX2 producing up to 907g of filament per hour
- Filament Tolerance: It maintains a diameter tolerance of +/- 0.05 mm
- Price: starts at 19000 eur (Extruder, Spooler, Shredder)

B. *Felfil Evo* [1]

- Build Quality: The Felfil Evo is available as both a pre-assembled unit and a DIY kit
- Temperature Range: It can heat up to 30°C, which is sufficient for materials like PLA, PETG, ABS, HIPS, and TPU
- Extrusion Speed: The Evo has extrusion rate of 100-150 grams per hour
- Filament Tolerance: It has a tolerance of +/- 0.07 mm
- Ease of Use: The Evo is relatively easy to assemble and use, especially for beginners
- Price: 2700 eur (Extruder, Spooler, Shredder)

Filabot EX2 is more suitable for users needing higher extrusion speeds and a wider range of material compatibility. **Felfil Evo** is a cost-effective option for those who are okay with slower speeds and need a simpler setup.

III. Recycling ratios of new and recycled Material for FDM 3D Printing Filament

The ratio of new to recycled material in FDM 3D printing filament depends on the quality of the recycled filament, the recycling technology used, and the requirements for the final prints [4], [5], [6]. Typical ratios fall within the following ranges:

A. *70% New / 30% Recycled Material*

- The most commonly used ratio for recycling.
- Ensures good quality and mechanical properties of the filament.
- The new material adds stability and consistency to the filament, preventing printing issues such as poor layer adhesion or print failures.

B. *50% New / 50% Recycled Material*

- A balanced ratio used when the recycled material is well-processed (uniform granules, free of impurities).
- Mechanical properties may be slightly reduced but remain sufficient for many common applications, such as prototypes or decorative objects.

C. 30% New / 70% Recycled Material

- Less common but feasible when using high-quality recycled filament.
- Mainly used for low-demand models or applications where high strength and precision are not critical.
- Requires careful quality control of the recycled material.

D. 100% Recycled Material

- The most challenging option, as recycled filament may suffer from instability and reduced quality (inconsistent diameter, weaker mechanical properties).
- Suitable only for experimental applications or when specialized recycling equipment is available.
- Not recommended for precise prints or critical functional parts.

E. Factors Affecting the Ratio

1. Material Type: PLA and PETG are easier to recycle, whereas ABS or nylon require more advanced processing techniques.
2. Recycling Quality: Proper granulation and re-extrusion processes are crucial to avoid impurities and polymer degradation.
3. Printing Purpose: Higher recycled content is acceptable for decorative objects, whereas functional parts require a higher proportion of new material.

The optimal ratio depends on the specific project requirements, but for most applications, a 70% new to 30% recycled material ratio is recommended to ensure good print quality and stability.

IV. PREFFERED MATERIAL TYPE

PLA (Polylactic Acid) is the material used in our 3D printing education process. The advantages of **PLA** make it the ideal choice. PLA is made from renewable resources like cornstarch or sugarcane, which aligns with our sustainability goals. Its **ease of use** and **low melting point** allow students to work with it confidently, reducing print issues like warping and ensuring reliable results. Additionally, **PLA is non-toxic**, making it safe for educational environments, as it doesn't release harmful volatile organic compound (VOC) during printing. Finally, the **high-quality finish** and **detail** it produces are perfect for student projects, prototypes, and visual demonstrations. These characteristics make PLA the ideal filament for use exclusively in the educational process.

A. The price of PLA pellets

The price of PLA pellets for recycling into filament varies depending on the source and material quality. Generally:

1. New PLA Pellets: These cost approximately 200eur for a 25 kg bag, which translates to about 8eur per kilogram. These are high-quality pellets used for professional-grade filaments and 3D printing applications [7].
2. Recycled PLA Pellets (rPLA): These are often more environmentally friendly and may cost slightly less. They are typically produced from recycled PLA waste and are available in various colors and formulations. Specific prices depend on the supplier and batch availability, as recycled materials can fluctuate in price due to sourcing challenges

B. Calculations

The following table calculates the cost of producing 1 kg of recycled filament at various ratios of new to old material, assuming the cost of new material is €8/kg, and the old material is considered free (€0/kg):

Table 1. Price of production

Ratio of New/Old Material	Cost of New Material (€)	Cost of Old Material (€)	Cost per 1 kg of Recycled Filament (€)
100% New / 0% Old	**8.00**	**0.00**	**8.00**
70% New / 30% Old	**5.60**	**0.00**	**5.60**
50% New / 50% Old	**4.00**	**0.00**	**4.00**
0% New / 100% Old	**0.00**	**0.00**	**0.00**

The cost of old material in our scenario is zero, as we have collected enough old material over the previous years of laboratory functioning. Cost per 1 kg of filament = (Proportion of new material × cost of new material) + (Proportion of old material × cost of old material). A higher proportion of recycled material significantly reduces the overall production costs.

Here's a comparative table of the additional costs and time required to produce 1 kg of filament using the Felfil EVO and Filabot EX2 extruders:

Table 2.Additional costs

Extruder	Production Rate (kg/hour)	Power Consumption (W/hour)	Time to Produce 1 kg (hours)	Energy Cost (€/kWh)	Cost to Produce 1 kg (€/kg)	Notes
Felfill EVO	**0.15**	**80**	**6.67**	**0.20**	**0.107**	**Low production rate**
Filabot EX2	**0.907**	**500**	**1.10**	**0.20**	**0.11**	**High production rate, suitable for large-scale recycling operations.**

Felfill is slower, making it ideal for small-scale or hobbyist recycling. Filabot EX2 is faster and better suited for industrial or large-scale use, offering higher productivity.

To calculate how long it would take to produce 35.3175 kg (annual consumption) of filament using the Felfil EVO and Filabot EX2 extruders, we use their production rates:

1. Felfill:
   - Production rate: 0.15 kg/hour
   - Felfill: Approximately 235.5 hours to produce 35.3175 kg of filament.
2. Filabot EX2:
   - Production rate: 0.907 kg/hour
   - Filabot EX2: Approximately 38.9 hours to produce 35.3175 kg of filament.

Table evaluating various ratios, cost savings, and the payback period for the proposed recycling machines.

Table 3. Evaluations

Device	Price (€)	Recycling Ratio (New:Recycled)	Cost per kg (€)	Electricity Cost (€)	Total Cost per kg (€)	Savings per kg (€)	Savings on 35.3175 kg (€)	Payback Period (kg)
Felfill	2,700	50:50	4.00	0.10	4.10	25.90	916.42	104.00
		70:30	5.60	0.10	5.70	24.30	858.61	111.59
		100:0	8.00	0.10	8.10	21.90	773.59	122.45
		0:100	0.00	0.10	0.10	29.90	1,057.88	90.00
Filabot EX2	19,000	50:50	4.00	0.10	4.10	25.90	916.42	733,59
		70:30	5.60	0.10	5.70	24.30	858.61	781.89
		100:0	8.00	0.10	8.10	21.90	773.59	867.57
		0:100	0.00	0.10	0.10	29.90	1,057.88	635.45

The Felfill extruder has a faster payback period due to its lower initial cost, achieving breakeven after producing between **90.56 to 123.86 kg** of filament, depending on the recycling ratio. Based on the estimated **annual filament consumption of 35.3175 kg** in 2024, the Felfill would reach payback in approximately **2.6 to 3.5 years**.

The Filabot EX2, while more expensive, benefits from industrial-scale production, and would require **636.45 to 870.64 kg** of filament to break even, assuming lower production costs. With **35.3175 kg** of filament production annually, the Filabot EX2 would require **18.0 to 24.7 years** to achieve payback.

C. Cost of Replacing Components:

Felfil Common parts like **nozzles** and **feed gears** can cost around **€10–€100** depending on the part, and replacing worn-out components may incur these costs annually. **Filabot EX2** replacement parts like **motors** or **heating elements** can cost upwards of **€200–€500** for major components. Regular parts replacements can range between **€300–€700** annually, depending on usage and how aggressively the machine is used.

V. Discussion

The Felfill Evo is priced at €2,700, making it significantly more affordable compared to industrial-scale machines like the Filabot EX2 priced at €19,000. This lower cost is especially important for educational and research environments where budget constraints are common.

The Felfill extruder produces 0.15 kg of filament per hour, which aligns well with the laboratory’s material consumption of approximately 35.3175 kg per year. Given that the demand for filament is not extremely high, this machine can meet the needs without unnecessary excess capacity. In comparison, the Filabot EX2 can produce 0.907 kg per hour, making it more suitable for industrial-scale operations, but its higher production capacity would be underutilized in a laboratory setting, potentially leading to inefficient use of resources.

The Felfill Evo has a much faster payback period compared to the Filabot EX2, which would result in quicker cost recovery. For a recycling ratio of 50:50, the payback period for Felfill is around 3 years. In contrast, the Filabot EX2 would take approximately 21 years to recover its initial investment at the same recycling ratio. Considering the laboratory's material needs, the Felfill Evo’s smaller scale allows it to achieve a payback period within a reasonable timeframe, ensuring cost efficiency without excessive upfront expenditure. Without including labor costs, the payback periods are significantly shorter for the Felfill extruder, which reaches payback in approximately 3 years (depending on the recycling ratio). In contrast, the Filabot EX2 requires 21 years to break even, reflecting its higher initial cost and less favorable payback profile.

The Felfill Evo's simpler setup and operation make it ideal for educational environments, where students can directly engage with the recycling process, learn about filament production, and experiment with various recycled materials. The low operational and maintenance costs further enhance its fit for the lab's needs.

In this case, we will exclude the labor costs for operating the machines since it is assumed that the devices will be operated by students as part of their educational process. This means that we will focus on material and service costs only for the calculations.

Based on the material needs of the 3D printing laboratory at the Faculty of Management Science and Informatics (FRI UNIZA), it appears that a device with a lower initial cost and smaller production capacity, such as the Felfill extruder (Felfill Evo), would be a more suitable choice for the laboratory's scale.

VI. Conclusion

Given the relatively modest filament requirements at the FRI UNIZA 3D printing laboratory, coupled with budget constraints and educational goals, the Felfill Evo offers a more cost-effective and appropriate solution. Its lower initial cost, sufficient production capacity, and faster payback period make it a suitable choice for meeting the laboratory's needs efficiently, while avoiding the excess capacity and high costs associated with larger machines like the Filabot EX2.

This analysis suggests that investing in smaller-scale filament recycling machines like Felfill Evo aligns well with the laboratory's goals, allowing for effective material recycling and educational engagement without unnecessary overhead.

Although the Felfill Evo is an affordable and useful machine for recycling filament in educational and small-scale environments, its lower precision and potential for inconsistent filament quality should be carefully considered. These factors could negatively affect the 3D printing process, resulting in defective prints and inconsistent print quality. Therefore, while it serves as a cost-effective option, careful monitoring and maintenance will be required to ensure it meets the desired standards for quality and consistency in prints.

References

[1] "Felfil Evo Filament Maker," Felfil, [Online]. Available: https://felfil.com/felfil-evo-filament-maker-landing/?v=058f38ac9331.

[2] "Filabot Original EX2," Filabot, [Online]. Available: https://www.filabot.com/products/filabot-original-ex2?srsltid=AfmBOop_bHQC_jUV7LKyszMNbl6nVWx8gOVaC617SCzNk7XR_eN4NYku.

[3] L. Formanek, A. Tupy, L. Cechovic, and P. Sarafin, "Benefits of Teaching 3D Printing in the Education Process at the Faculty of Management Science and Informatics," University of Zilina (Slovakia).

[4] "Synthesis and Properties of 3D Printed Polymers," MDPI, [Online]. Available: https://www.mdpi.com/2073-4360/15/9/2165.

[5] "Polymer Composites for 3D Printing," MDPI, [Online]. Available: https://www.mdpi.com/2073-4360/13/8/1222.

[6] "PLA Shredded Filament," 3Devo, [Online]. Available: https://support.3devo.com/pla-shredded.

[7] "PLA Pellets," 3DXTech, [Online]. Available: https://www.3dxtech.com/products/pla-pellets-1.