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Improving 3D printing sustainability in academic research: a PLA recycling initiative

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Integrating sustainability into a research laboratory and expanding this integration to a campus-wide initiative while promoting chemical education is a crucial challenge that scientists need to tackle for the current and future generations. Herein, we present an initiative for sustainable repurposing of three-dimensional (3D) printing waste materials made of poly(lactic acid) (PLA). First, we describe the methodology used to prepare recycled 3D printed filaments from 3D printed waste produced in our laboratory, from shredding to filament extrusion, including a detailed thermal and mechanical characterization to benchmark the properties of the resulting filament against a commercial one. Once this laboratory-scale protocol is established, we describe how we implemented a circular, campus-wide initiative to repurpose 3D printed waste generated at the Université de Montréal (UdeM), Canada, and how we use this initiative as an educational tool to promote responsible use of materials among the students, researchers and members of the university. The residues are collected university-wide from research groups and digital fabrication space communities before being processed back into filaments suitable for 3D printing that are redistributed to the university community, providing a circular alternative for their future 3D prints. A website dedicated to the initiative allows us to educate the university community about PLA and to promote this initiative as an example of a solution to address global material consumption issues. This initiative establishes a sustainable framework for the collection, recycling, and redistribution of 3D printing filaments, promoting a circular economy model within the university as well as contributing to educate the community on the responsible use of materials. We believe that sharing our journey toward promoting sustainability within our research community and beyond will inspire other researchers to promote such initiatives within their own community.

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Sustainability spotlight

The growing accessibility and use of fused filament fabrication (FFF) three dimensional (3D) printers within academic settings generate substantial poly(lactic acid) (PLA) waste (10 to 40% in weight) from supports and failed prints. Yet, PLA rarely degrades naturally, and its up/recycling options are scarce, especially for universities. Addressing this waste stream is critical for 3D printing sustainability. Herein, we present a 3D printing sustainability initiative suggesting some pathways to transform a laboratory-based effort to a campus-wide adaptable framework. Our work aligns with the UN SDG 12 – Responsible consumption and production. In the case study we present, we aim to reduce the 3D printed waste by repurposing PLA, while taking the opportunity to build awareness within the research community around this issue.

Introduction

Given the growing accessibility of 3D printing, whether through the decreasing cost of printers and materials and even the availability of online design models, additive manufacturing is becoming increasingly popular in academic research settings, including university research laboratories and digital fabrication spaces. In chemistry research specifically, fused filament fabrication (FFF) is now commonly used to print sample holders, molecular models and missing parts of research equipment, to name a few.[1–7] However, this democratization also generates a significant amount of waste, mostly made of poly(lactic acid), PLA.[8–10] Indeed, in FFF 3D printing, residual materials come from support structures required to hold printed parts, as well as from failed prints. According to well-known FFF 3D printer manufacturers, between 10 and 40% (by weight) of filaments used in FFF are discarded.

Despite these large quantities of waste, very few solutions exist to recycle and upcycle these residues produced by non-industrial users, and they typically end up in garbage bins and landfills.[11] PLA is a biodegradable polymer under industrial composting conditions, synthesized from biomass containing 2-hydroxypropanoic acid, such as starch-based materials[12] (see

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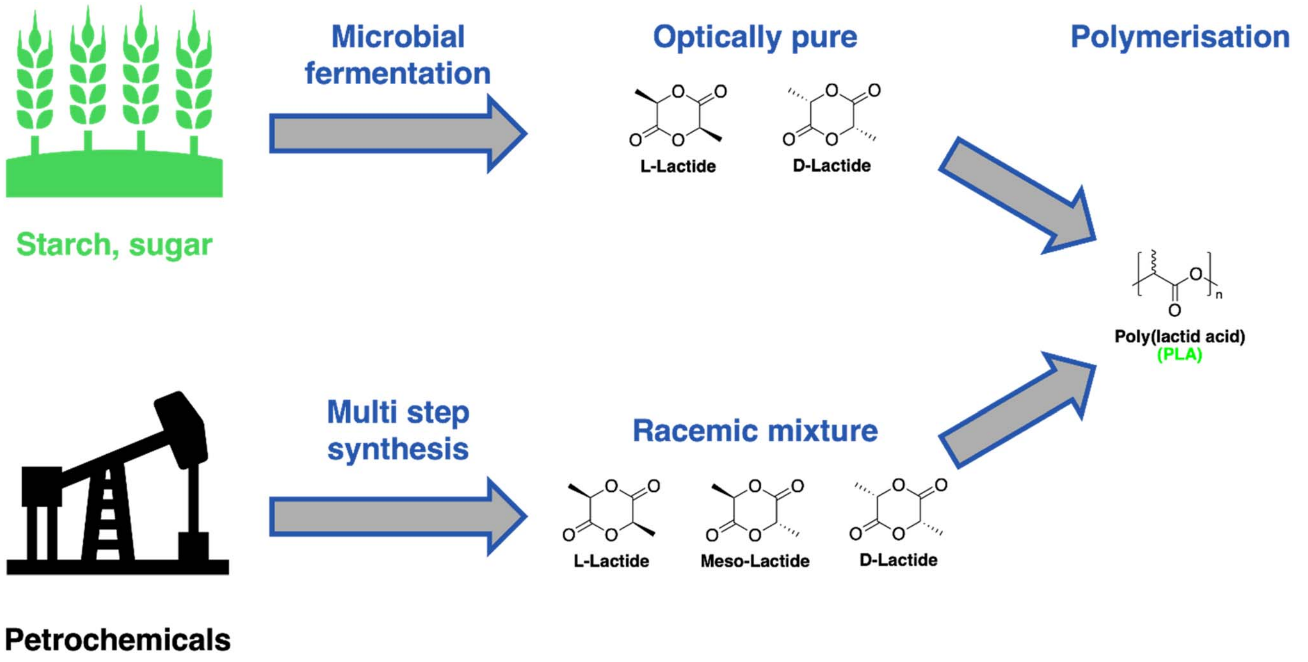

Fig. 1 Principal synthesis pathways to poly(lactic acid).

Fig. 1 for additional details). Biodegradation only occurs at high temperatures, not under regular environmental conditions, meaning that in soil, only about 1% of PLA decomposes after 100 years.[13] Therefore, industrial composting facilities are required to process PLA. Yet, such facilities are limited and not easily accessible in Québec, Canada. Compared to the rest of the world, PLA is often disregarded by recycling facilities due to the complexity of material separation. In the United Kingdom, PLA is only recycled by specialized private entities like Filamentive.[14,15] A great example of progress in the recycling of PLA is demonstrated by South Korea, where a partnership between the South Korean government and TotalEnergies-Corbion has led to the development of special recycling programs for PLA-based materials.[16,17]

In terms of recycling, PLA generally cannot be recycled in municipal facilities across Québec. This is the case in Montréal:biodegradable plastics, which include PLA 3D printed waste, are not accepted in recycling bins. While a few companies offer recycling services, these are often paid services, or they restrict the type of wastes accepted to those made from the company's own filament products, in order to maintain the quality of the recycled filament. As a result, such services are not generally suited to the needs of research settings such as the Université de Montréal.

To fill this gap in 3D printing sustainability in an academic research setting, we established and operationalized a full framework for collection, recycling, and redistribution of recycled PLA filaments university-wide, including research labs and digital fabrication spaces. Our initiative stands as a free service for all the academic community, in an effort to reduce plastic waste and promote a cradle-to-cradle approach for the life-cycle of PLA.[18] This is well aligned with the United Nations (UN) Sustainable Development Goals (SDGs), specifically Goal 12, which aims for responsible consumption of materials. Although some digital fabrication spaces offer recycling options and life cycle assessment (LCA) studies have been conducted from an engineering perspective on PLA recycling, we believe it is important to integrate all aspects under a single umbrella of 3D printing sustainability for our community and to link this effort to the UN SDGs.[19–23] Our initiative leads as an example of a tangible effort towards sustainability for students, researchers and members of our university community, raising awareness on the issue of responsible consumption and providing a simple solution to make change in their consumer behavior. Exposure of information about the initiative on a website also allows us to provide education for the university community on the environmental impacts of using PLA, focusing on the importance of finding new solutions to plastic waste in accordance with the cradle-to-cradle philosophy. It is also used to promote the initiative, ensuring that the sustainable solution we developed benefits the wider research community who are using 3D printing in their research.

Herein, we present our journey that encompasses the development of a methodology to repurpose PLA waste from our research laboratory to its campus-wide integration, leveraging this initiative, named FilUM, as a chemistry education tool. Our team developed a robust protocol to transform our 3D printed residues into recycled printable filaments. This in-house recycling process covers everything from PLA-based 3D printing waste material collection to the distribution of recycled PLA filaments to the university community. First, the experimental work linked to the recycling of the PLA-based 3D printed waste material is discussed, highlighting the multistep process based on desktop extrusion technology. Furthermore, the challenges associated with material collection and outreach on a campus-wide scale are discussed. Finally, a case study where the recycled filaments are benchmarked against a commercial counterpart enables us to confirm the viability of the recycling process to obtain print quality recycled filaments that can be confidently redistributed to the university research community.

Materials and methods

Material preparation

PLA 3D printed waste was collected from our research laboratory, other university research laboratories and the digital fabrication spaces across the Université de Montréal. The materials were separated according to their color. The material was then shredded 3 times to obtain particles with a diameter less than 2.5 mm using a FelFil Shredder+. Larger discarded materials were pre-treated by breaking it apart into pieces of less than 50 mm length. The shredded material was then sieved using a 3D printed multi-stage sieve (Fig. S3 in the SI), to limit the distribution of the dimensions of the shredded granulate. Finally, the granulate was dried overnight at 100 °C before extrusion. As a control, a white PLA filament spool (1 kg) of 1.75 mm diameter from Econofil™ was employed.

Extrusion (spooling)

Extrusion of the recycled material was carried out using a 3devo Filament Maker ONE desktop extruder. The extrusion zone is composed of 4 controllable heater elements set at 180 °C. The extruder speed was set at 5 rpm and the fan speed at 40%. The diameter of the filament was monitored using the DevoVision software from 3devo which is connected to an optical sensor placed before the filament puller. Around 30 g of the pre-processed material is deposited in the entry hopper. Once extrusion starts, 5 to 10 min of stabilization are required to obtain a proper filament diameter of *ca.* 1.75 mm. At this point, more material can be added to the extruder, and the extrusion can be completed once enough filament has been spooled.

Thermal analysis

Thermogravimetric analysis (TGA) was employed to evaluate the thermal stability of the samples using a TA instruments TGA 5500 apparatus. Approximately 8 mg of the sample was placed in an aluminum crucible and subjected to a heating ramp from 25 °C to 600 °C with a heating rate of 10 °C min^{-1}. The furnace was purged with dry N_2 with a flow rate of 25 mL min^{-1}. Differential scanning calorimetry (DSC) was employed to determine the transition temperatures and crystallinity of the prepared samples using a TA instruments DSC X3. Approximately 4 mg of the sample was loaded in a TA Tzero aluminum pan and subjected to two analysis cycles between 0 °C and 200 °C at a heating rate of 10 °C min^{-1}.

Mechanical analysis

The mechanical properties of the prepared samples were evaluated using an Instron 5565 universal testing machine. Samples approximately 25 mm in length were analyzed with a strain ramp of 10% deformation per min. Geometric parameters (length and diameter) were adjusted for each sample analyzed.

Spectroscopic analysis

Fourier-transform infrared spectroscopy (FT-IR) was employed to verify the chemical nature of the recyclable material using a Thermo Fisher Scientific Nicolet 4700 FT-IR spectrometer with an attenuated total reflectance (ATR) accessory equipped with a diamond crystal. A total of 16 background scans and 16 sample scans with a resolution of 4 cm^{-1} were averaged to obtain the IR spectra between 4000 cm^{-1} and 600 cm^{-1}.

3D printing (fused filament fabrication)

3D printing of a standard 3DBenchy was conducted using a Prusa MK3S+. 3DBenchy is an open-source model serving as an industry standard for benchmarking and stress testing in FFF. The design used can be found at https://3dbenchy.com. It features complex geometries that are difficult to print with perfect dimensional accuracy. It was selected to facilitate a direct visual and structural comparison between the print quality of the commercial and recycled filaments. Standard PLA printing parameters were used. Nozzle and bed temperatures were set at 210 °C and 60 °C respectively. The printing speed was set at 50 mm s^{-1} and a layer height of 200 μm was employed.

Results and discussion

Repurposing PLA 3D printed waste: method development

The pre-processing of a raw material is a common occurrence for most processing methods. For most mechanical recycling methods of polymers, a multi-step process is needed to obtain a proper starting material. The first step is material sorting. In large scale applications, the recycled material is often sorted by spectroscopic identification through NIR reflectance or X-ray screening.[24,25] Unwanted materials can then be removed by blowing air jets on the conveyed sections. After sorting, the material is dried and conveyed further to the shredding pre-processing unit.[26] Shredding is often used to obtain flakes of recycled material which can then be washed and returned to the market or processed into recycled objects through extrusion, molding or blowing.[27]

In the case of recycling 3D printed objects prepared through an extrusion process on the lab scale, four key pre-processing steps can be identified as follows: sorting, shredding, sieving and drying. The recycling process employed here is based upon different studies of lab scale recycling processes.[28–30] We modified our process to perform it adequately with our equipment by using additional steps like granulate sieving with 3D printed sieves. The recycling process is schematized in Fig. 2. The raw material is manually sorted based on color and identified with FT-IR spectroscopy (Fig. S1 in the SI). After this identification step, the material is shredded to obtain a granulate of appropriate size for extrusion (2.5–4 mm). During the development of this method, we found that for PLA, three cycles of shredding were necessary to ensure an appropriate size of the granulate

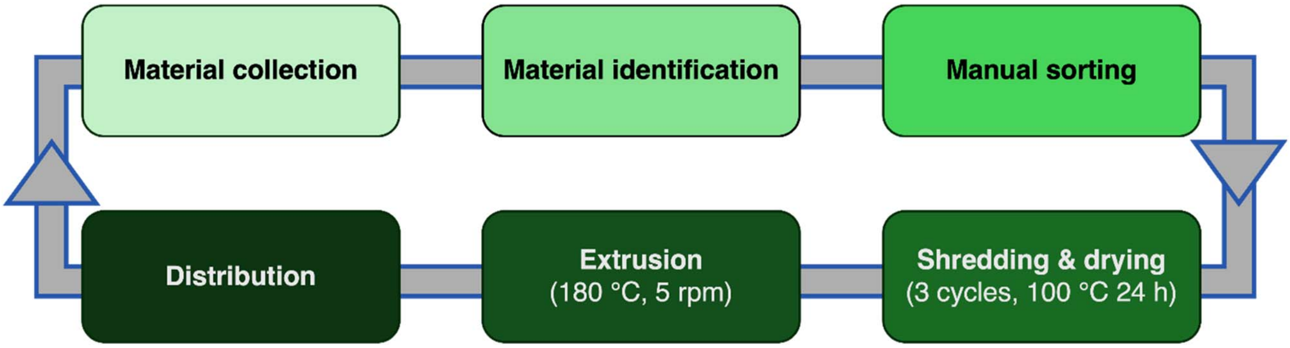

Fig. 2 Holistic view of the PLA recycling process of the FilUM initiative.

(Fig. S2 in the SI shows the evolution of the granulate with shredding cycles). However, disparities in the granulate size could prohibit thermal transfer inside the extrusion barrel and lead to inhomogeneity in the extruded filament. Längauer *et al.* showed that for single screw extrusion processes, the influence of pellet shape can lead to overpressure and melt temperature overshoots which in turn can lead to material degradation.[31,32] To avoid this problem, we 3D printed a multi-stage sieve (800 µm, 500 µm) to allow the preparation of a homogenous granulate size distribution. Photographs of the multi-stage sieve are shown in Fig. S3 in the SI. Following this process, we calculate that there is a material loss of *ca.* 5% (calculated on a 20 g scale). The resulting granulates were then dried overnight at 100 °C to remove moisture. Water is a well-known hindrance for extrusion processes, especially for materials that can be hydrolyzed such as poly(esters) like PLA.[32–34] This effect is even more relevant for modern extrusion methods such as FFF 3D printing.[35] However, the main drawback of the proposed method is the wide variety of raw materials. Differences in color, molecular weight and additives entering the composition of the filaments cannot be accounted for with our pre-processing method. Indeed, the identification of these parameters would be troublesome in the campus-wide initiative context. For these reasons, our PLA granulates are a blend of different starting filaments of similar color that can contain various additives or display discrepancies in molecular weight. 3D printing PLA based filaments are already produced by a large number of manufacturers which do not necessarily disclose the nature of the additives present to give their filaments properties or colors. Our initiative is based upon sorting PLA materials through color only. However, additives can impact mechanical and optical properties of the samples especially when considering the impact on crystallinity.[36–38]

The extrusion of the pre-processed material with a desktop extruder is a relatively straightforward process. The pre-processed granulate is deposited in the entry hopper and the extrusion flow and diameter are monitored to identify stabilization. Once the filament has reached a stable diameter, the puller speed can be adjusted automatically through the extruder software to ensure adequate filament diameter. For both collected materials (white and blue PLA), a temperature of 180 ° C on the full barrel length together with an extruder screw speed of 5 rpm was deemed adequate to obtain print quality filaments. Fig. 3 presents the diameter as a function of time for the pre-processed blue PLA granulate. In this figure, an initial stabilization time of around 200 s can be observed, followed by a stable extrusion in the filament diameter printability zone for the remainder of the extrusion. This tool allows a quick determination of filament printability and could facilitate extruder tuning for diverse materials.

Once the filament is pulled, the spooling speed is automatically determined from the puller and extrusion speed to ensure proper spooling of the extruded filament. This method allowed us to obtain recycled filaments of white and blue PLA granulate ready to be used for 3D printing applications. Photographs of the recycled filaments are shown in Fig. S4 in the SI.

Implementation of a 3D printing sustainability initiative across campus

Once the method to prepare print quality filaments from PLA 3D printed waste is established, we wanted to implement it into a campus-wide framework to operationalize our initiative for sustainable repurposing of printing waste materials made of

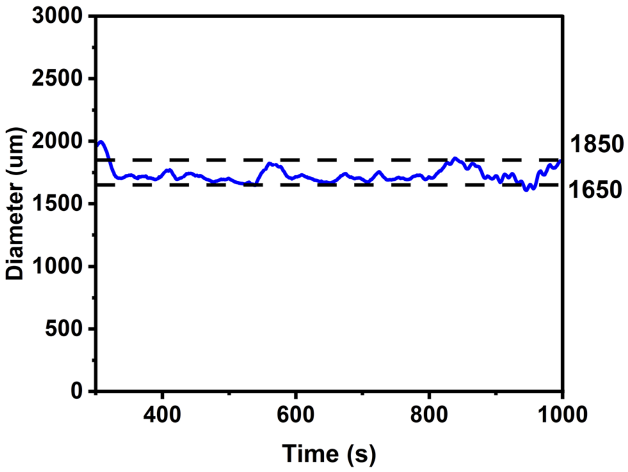

Fig. 3 Filament diameter as a function of time for the blue recycled PLA extruded at 180 °C with a screw speed of 5 rpm. The dotted black lines represent the upper and lower acceptable limits of print quality filament diameter.

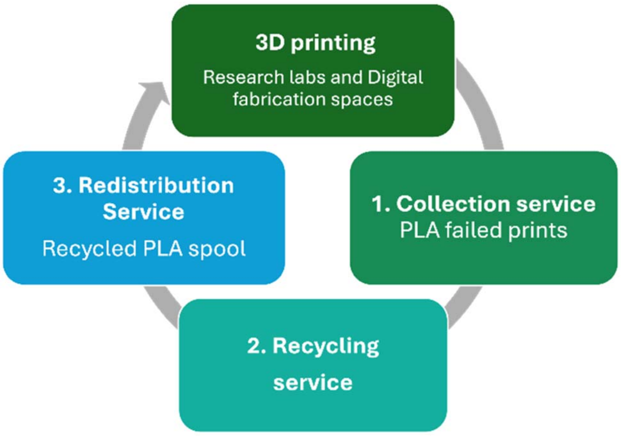

Fig. 4 Framework of the FilUM initiative showing the different steps and entities at play from waste material collection to distribution.

PLA. The framework is divided into three main components: a collection service, a recycling service and a distribution service, as illustrated in Fig. 4. In the discussion below, we present some possible pathways to implement, operationalize and promote 3D printing sustainability in a university setting, while highlighting how such initiatives can be leveraged as a tool for chemistry education, more specifically in the context of the UN SDGs. It is important to emphasize the fact that this framework stands as a case study that would need to be adapted to the realities of each setting and we hope that these general guidelines will inspire the community to develop a sustainable approach that best fits their needs.

Collecting the 3D printed PLA waste. In our academic context, printing waste materials made of PLA originated from two major sources: digital fabrication spaces and research laboratories. In our specific case, most of the digital fabrication spaces are located across libraries (there are twelve libraries at the Université de Montréal, six of them offering a digital fabrication space). Using the library network, we were also able to reach two other fabrication spaces across campus, one from the Optometry School, and the other from the Architecture School. The second source of failed prints are participating research labs, which are from various departments, such as Medicine, Computer Science and Operation Research, as well as Chemistry. The diversity of the disciplines participating in this initiative highlights to which extent FFF 3D printing is democratized, as well as to which extent a 3D printing sustainability initiative can reach out to community members beyond those in the chemistry community. It further shows that such initiative can be leveraged as a tool to familiarize the community with the UN SDGs and their importance.

All the printing waste materials made of PLA were shipped using internal mailing in boxes, which is accessible to any employee across campus, and then centralized in the Hubert-Reeve's library located in the same building as our research laboratory. Having the possibility to centralize the collected waste near the location of the recycling step is an important aspect to consider when such an initiative is deployed. A storage room was also dedicated to this initiative in our laboratory space, where the boxes are stored on a shelf in a controlled temperature room. So far, after 6 months of collecting PLA failed print, we gathered approximately 30 kg of material. As a side note, used spools from the digital fabrication spaces are also kept in that storage room, so they can be reused for spooling the recycled PLA filaments. Another path to explore for the collection of the 3D printed waste is to establish a collaboration with the Occupational Health and Safety (OHS) Team in the research setting. This collection pathway would be an interesting avenue in the case of a laboratory generating a high-volume of PLA waste, since the OHS Team can offer regular and/or on-demand pickups as they are used to doing with chemical waste.

Recycling the 3D printed PLA waste. The method developed and discussed in the previous section is conducted in our research group by members of the group, allowing the transformation of PLA printing waste materials back into filaments suitable for 3D printing. Once the recycled filament is produced, a rewinder is used to transfer the recycled PLA filaments onto a used spool provided by the digital fabrication spaces, in agreement with a circular approach for the use of materials.

Redistribution of the recycled PLA. The recycled PLA spools are redistributed to the research community and users of the university teaching, research and digital fabrication space communities. There are few possible avenues to realize this redistribution: one is by working with a (chemistry) store or bookstore within the university. In that case, recycled PLA spools can be bought at a nominal price *via* either the website, or directly on the store website, and be retrieved in the participating store. Another avenue would be giving the spools back to selected candidates from the groups or associations based proportionally on their participation in the initiative. However, it is important to note that it takes a significant quantity of failed prints to produce a recycled PLA filament spool. Thus, the delay before delivery can be variable according to production of failed prints and/or waste from the participants. Another factor that must be taken into account is the quality of the recycled PLA filaments produced. Indeed, since there is a certain heterogeneity in the printing waste materials, the diameter of the recycled filaments produced can vary more than for a commercially available filament (even though it falls within the printability zone of the filament diameter, as discussed in the previous section) and the mechanical properties could be impacted by the recycling process (*vide infra*). Therefore, the quality of prints made from the recycled filaments can differ from a commercially available PLA filament. It is important to inform the possible users of those differences before redistribution.[39] For users that are more sensitive about the diameter variation, a solution within the 3D printing community is the installation of a filament width sensor on the user's 3D printer, which allows the adjustment of the extrusion coefficient throughout a print to reduce the effect of the variable diameter from recycled filaments. It is also interesting to note that the failed prints from the PLA recycled filaments can be recycled again if mixed with regular PLA to yield sufficient mechanical properties for applications.[40] This way, users of the recycled filaments can participate in the initiative without additional sorting.

Outreach. Moreover, the outreach aspect of the initiative is an important part of the process for two main reasons: gathering more participants and educating the community on responsible consumption of materials, while taking this opportunity to familiarize them with the UN SDGs, more specifically with the SDG12. A key tool to cover this aspect was to create a website dedicated to the initiative. On the website, practical information can be found, such as a map showing the bin locations across the campus or statistics on the quantity of material collected and recycled. On the website, we also offer education on PLA from a chemistry perspective, explaining its origin, methods of disposal, services available for composting or recycling, *etc.* The goal is to offer a realistic picture of the lifecycle of this material, educate the community about its current use, and offer a few solutions for a more responsible way of using the material. We also developed a video explaining the initiative in collaboration with the digital fabrication spaces, where the recycling process of the PLA failed prints is detailed with footage within the laboratories. A QR code linked to this video can be found on every recycling bin for failed prints in the various digital fabrication spaces across campus, as well as in Fig. S5 in the SI. This QR code leads to the website dedicated to this initiative, where a survey can be found for the participants (this survey is also presented in Fig. S6 in the SI). Apart from the website dedicated to the initiative, affiliated websites, such as those of the libraries and the Vice-Rectorate of Research and Innovation, highlight the initiative on their page. An article in the university newspaper can also be prepared to promote the initiative. These ideas related to outreach are only a few of the many possibilities that can be explored to reach the broadest possible community within a setting where such an initiative is implemented. We believe that this promotion should be leveraged into an occasion to help the community discover the UN SDGs.

Case study: using a recycled PLA filament to 3D print

Having established an integrated recycling solution for the university community for 3D printed PLA waste, our next goal was to demonstrate that this recycled filament can be used to successfully 3D print samples. To do so, we have put together a case study where we first conduct a series of thermal and mechanical analyses to help benchmark the recycled filament to a non-recycled, commercial one before comparing the 3D printed parts prepared with recycled and non-recycled filaments.

Thermal properties. The thermal properties of the recycled PLA filaments were analyzed with the help of two techniques. The decomposition profiles of a commercial filament, and a blue (B) and a white (W) recycled filament are shown in Fig. 5a. The thermogravimetric analysis (TGA) shows a sharp decomposition at 365 °C for the commercial filament. The recycled white and blue filaments present a decomposition temperature of 363 °C. This small difference in decomposition temperature and appearance of the curve suggests that minimal material degradation occurred during the recycling process. Furthermore, this TGA analysis reveals that the thermal stability of the recycled filaments is not affected by the recycling process employed here. Table S1 in the SI shows the decomposition temperatures for all analyzed samples.

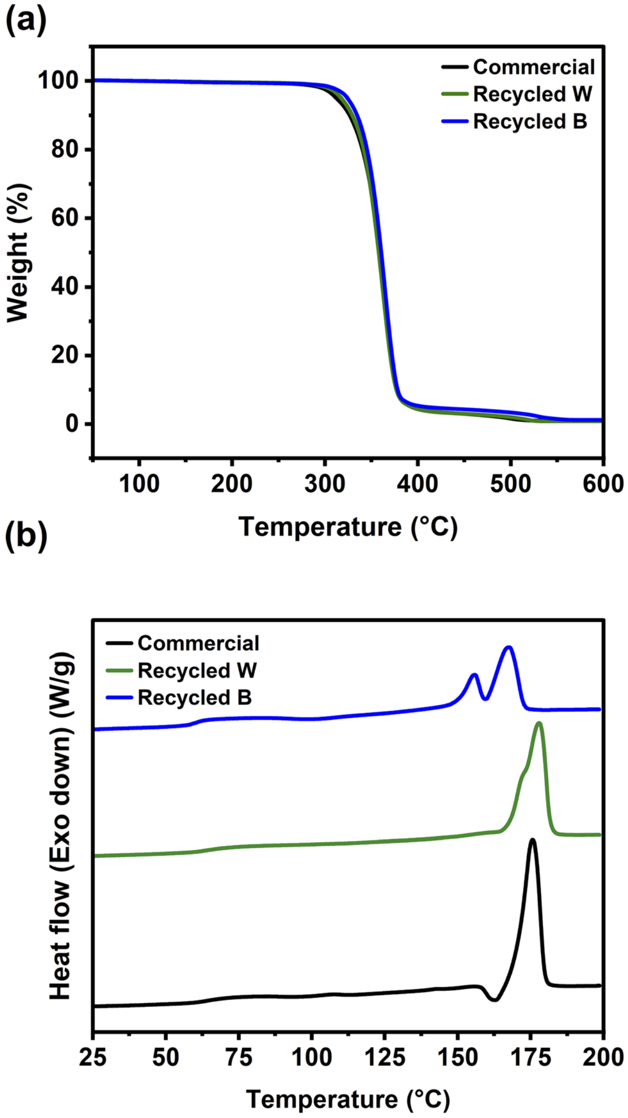

Fig. 5 (a) Thermogravimetric analysis of the prepared recycled filaments showing the weight % as a function of temperature. (b) First heating curve of a DSC experiment of the prepared recycled filaments showing the heat flow as a function of temperature. W and B stand for the white and the blue recycled filament, respectively.

Subsequently, differential scanning calorimetry (DSC) was employed to observe the thermal transitions of the filaments, as shown in Fig. 5b. The first thermal event discernible on the DSC thermograms of the samples is the glass transition temperature (T_g). This transition is identified at 66 °C for both the commercial white and recycled white filaments. However, the T_g of the recycled blue filament is at a lower temperature of *ca.* 60 °C. This difference could be explained simply by the nature of the additives or pigments added to the various filaments to give

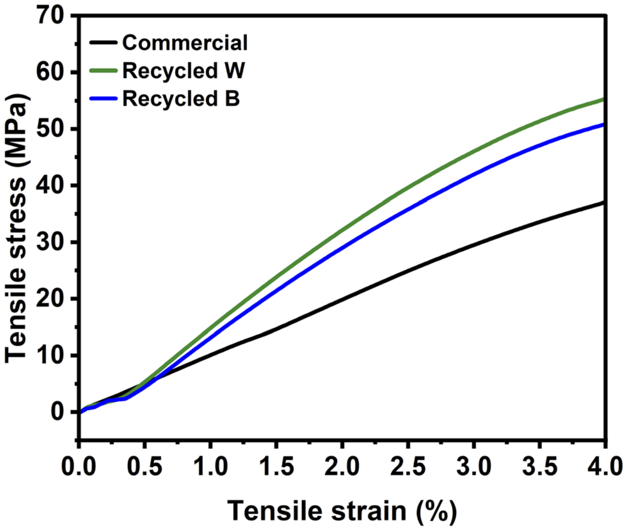

Fig. 6 Representative tensile stress as a function of tensile strain for the commercial and recycled filaments. This region was used to determine the Young's modulus of the materials. W and B stand for the white and the blue recycled filament, respectively.

them their color. When heating the materials further, we notice the occurrence of a small cold-crystallization (T_{cc}) for the recycled blue filament at around 100 °C which concurs with what is commonly reported for PLA-based materials.[12,41,42] This phenomenon is only visible in the recycled blue filament and could once again be due to slower crystallization kinetics (upon cooling) in the presence of additives. Commercial PLA also exhibits cold-crystallization just before the melting temperature (T_m) which is commonly referred to as a remelting process in the literature. This process includes a reorganization of the crystalline phase to a more stable state just before the melting temperature.[43]

The melt transitions of both commercial PLA and recycled white PLA are respectively at 176 °C and 178 °C. For the recycled white PLA, we observe a small shoulder towards the low temperature of the melting peak, indicating a distribution of crystal size in the system.[44,45] In the case of the recycled blue filament, two melting events are discernible, the first at 156 °C and the second at 168 °C. We believe that these two melting events correspond to different structures formed during the extrusion process; since the recycled blue polymer is composed of multiple starting material, this phenomenon could be due to molecular weight discrepancies between the starting material, where the lower T_m corresponds to crystals formed by chains of lower molecular weight. Further characterization beyond the scope of this project could be performed to identify the nature of these two peaks. Finally, the crystallinity of the filaments was evaluated by integrating the melting peaks of the samples. The commercial filament showed a crystallinity of 34% while the recycled white filament was higher at 38% and the recycled blue lower at 30%. These calculated crystallinity values are higher than what are observed for pure PLA but expected for composite based materials due to the nucleation promotion character of the various additives in filament formulations.[46–48] All reported thermal transitions and crystallinity values are available in Table S2 in the SI. The combination of TGA and DSC thermal analyses shows that our recycled material exhibits similar properties to commercially available PLA filaments even after the recycling process.

Mechanical properties. To compare the mechanical properties of the recycled filaments with the commercially available one, a standard tensile test on the length of the filaments was applied, as shown in Fig. 6. The evolution of tensile stress with strain is particularly linear for the commercial filament. Both recycled filaments show deviation from linearity beyond 3% strain; however, we notice that the slope differs for the recycled filaments. This change in slope leads to a higher modulus. The Young's modulus (E) of the materials was evaluated in the linear region for the commercial, recycled white and recycled blue filaments. The modulus E was calculated to be 1.0, 1.7 and 1.6 GPa respectively. Once again, the comparison of the mechanical properties for polymers of unknown molecular weight can be challenging. However, the objective here is to demonstrate that the recycled filaments are comparable to their commercially available counterparts. Aly *et al.* investigated the mechanical properties of pure PLA mixed with its recycled equivalent and showed a similar trend where recycled PLA exhibits a higher modulus than its virgin counterpart.[20]

3D printed results. To complete this case study, we compared the FFF 3D printing of a 3DBenchy using a commercial and a recycled filament. Fig. 7 presents the final printed

Fig. 7 3D printed 3DBenchys of 6.0 cm length, 3.1 cm width and 4.8 cm height from the (a) recycled white filament and (b) recycled blue filament. (c) Comparison of commercial and recycled filaments on a final 3D printed object.

object with (a) the white recycled filament, (b) the blue recycled filament and (c) a direct comparison between a print with a commercial blue filament and our recycled blue filament.

The prints obtained with the recycled filaments are of good quality for the average 3D printing user in the context of community accessible additive manufacturing. Further assessment of print fidelity and quality could be conducted to quantify the quality of prints; however, this is beyond the scope of our initiative since most users in the community use the service for personal use, research equipment prototyping or even 3D models for architecture studies. This case study allows us to compare the properties of our recycled filament with commercially available printing materials. In all aspects, it demonstrates that the recycled filament prepared thanks to the FilUM initiative is adequate for the scope of its use for the members of the university community. Furthermore, the materials science and sustainability principles behind the FilUM initiative could be integrated as part of a polymer chemistry or physical chemistry laboratory course. Multiple educational pathways for sustainable polymer chemistry experiments have already been proposed; however, none have been presented within the context of 3D printing.[49–55]

Conclusion

We developed a 3D printing sustainability initiative from the ground up, starting in our research laboratory before expanding to the wider academic community of our university. This example of a chemistry initiative integrated into the operations of the university is an example of a successful multidisciplinary collaboration through a simple framework that could be easily adapted to be implemented in other institutions. The core objective of the FilUM initiative is based on the effort to reduce plastic waste and promote a responsible consumption of materials which aligns with the 12th goal of the UN SDGs. The implementation of this initiative from the lab scale to a campus wide service enables responsible use of resources through outreach video demonstrations of the process and a webpage explaining the end-of-life options regarding degradability nature of PLA and required conditions. Now, we strive to continue our outreach activities to attract more users to take part in this recycling initiative. Education on the responsible use of materials and life cycle analysis are intrinsically linked to the initiative as a way to raise awareness among the university community. The equipment required to conduct this initiative is readily available, including desktop shredding and extrusion instruments. The accessibility of this instrumentation remains a key parameter to the applicability of such an initiative in different institutions, and we recognize that financial support is required for their acquisition. However, the value of educating students and community members about the material consumption taking part in this recycling process cannot be understated. Moreover, a case study was conducted to demonstrate that the recycled filament can be as good as commercially available printing material for the intended use herein. We found that the thermal stability of our recycled PLA filaments was identical to that of their commercially available counterparts. Thermal transitions and mechanical properties can vary a lot based on molecular weight and additive composition; however, for the applications targeted by the FilUM initiative, the properties exhibited by the recycled filaments are adequate. Finally, the printing of a 3DBenchy from our recycled filament compared to a commercially available one revealed no discernible qualitative differences, indicating that our recycled material can easily fulfill the needs of our community. FilUM is now growing as a part of the UdeM community to enlarge its outreach and enhance its impact on the students, researchers and members of our community and we sincerely hope that it will inspire other institutions to adapt it to their realities.

Conflicts of interest

There are no conflicts to declare.

Data availability

We confirm that the data supporting the submitted manuscript to *RSC Sustainability* entitled "Improving 3D printing sustainability in academic research: a PLA recycling initiative" have been included as part of the submitted manuscript and the supplementary information (SI). Supplementary information: TGA, DSC, FT-IR characterization, additional details on the recycling process and outreach. See DOI: https://doi.org/10.1039/d5su00959f.

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