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The Exploration of the CAD and 3D printing using Recycled Plastics

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Abstract:
The increasing concern over plastic waste and its impact on the environment has spurred a growing interest in sustainable solutions, including the recycling of plastics. This study explores the application of recycled plastic, specifically Polylactic Acid (PLA), in conjunction with 3D printing technology. The aim is to leverage the capabilities of Computer-Aided Design (CAD) and 3D printing to create products that not only address plastic waste but also promote environmental protection. The combination of recycled PLA and 3D printing offers a promising avenue for producing functional and customized objects, thereby contributing to circular economy principles and reducing the reliance on conventional plastic production methods.

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I. Introduction:

Plastic waste has become a pressing environmental issue, with its widespread presence in oceans, landfills, and ecosystems causing significant ecological harm. As the detrimental effects of plastic pollution become more apparent, there is an urgent need to find sustainable solutions to address this crisis. Recycling, particularly through innovative technologies, emerges as a critical approach to mitigate the negative impacts of plastic waste.

Recycling plastics through traditional methods often faces challenges due to factors such as contamination, limited sorting capabilities, and downcycling. However, the fusion of recycling efforts with advanced technologies like 3D printing holds great potential in transforming plastic waste into valuable resources. One such recyclable plastic gaining traction is Polylactic Acid (PLA), a biodegradable and bio-based polymer derived from renewable sources such as corn starch or sugarcane.

The utilization of PLA in 3D printing aligns with the principles of the circular economy by enabling the creation of new products from recycled materials. The synergy of Computer-Aided Design (CAD) software and 3D printing technology empowers designers and manufacturers to develop intricate and customized objects with reduced material wastage. This approach not only diverts plastic waste from landfills but also reduces the demand for virgin plastics and the associated environmental impacts of their production.

In this context, this study aims to explore the application of recycled PLA using 3D printing technology as a means of addressing plastic waste and promoting environmental protection. By harnessing the capabilities of CAD and 3D printing, the study seeks to demonstrate the feasibility of producing functional products with recycled PLA. The investigation encompasses the challenges and opportunities associated with utilizing recycled PLA, the design considerations in CAD modeling, the technical aspects of 3D printing, and the broader implications for sustainable manufacturing practices.

Types of recycled plastics good for 3D Printing

Several types of recycled plastics are suitable for 3D printing, each with its own characteristics and advantages. The choice of recycled plastic for 3D printing depends on factors like material properties, printing capabilities, and intended applications. Some common types of recycled plastics used in 3D printing are:

Recycled PLA (rPLA)**:** Recycled PLA is a popular choice for 3D printing due to its biodegradability and ease of processing. It's derived from renewable sources like corn starch or sugarcane and is known for its low toxicity and minimal warping during printing. rPLA retains many properties of virgin PLA, including low odor, ease of printing, and good layer adhesion. Using recycled PLA in 3D printing contributes to sustainability efforts and reduces the demand for new plastic production.

Recycled PET (rPET)**:** Recycled PET is widely used in various industries, including packaging and textiles. It can also be used in 3D printing, although it requires careful processing due to its higher melting point compared to PLA. rPET is known for its durability, strength, and resistance to moisture and chemicals. It's suitable for creating functional parts and prototypes, making it a viable option for 3D printing applications that require robustness.

Recycled ABS (rABS)**:** ABS is a common thermoplastic used in 3D printing due to its strength, impact resistance, and post-processing capabilities. Recycled ABS is suitable for 3D printing when combined with virgin ABS to maintain desired mechanical properties. rABS can be used for functional prototypes and end-use parts that require higher temperature resistance and durability.

Recycled Nylon (rNylon)**:** Recycled nylon is known for its strength, flexibility, and excellent layer adhesion. It's suitable for producing strong and durable parts, making it a popular choice for applications that require functional prototypes and components subject to mechanical stress. rNylon's heat resistance and low friction properties also make it suitable for certain engineering applications.

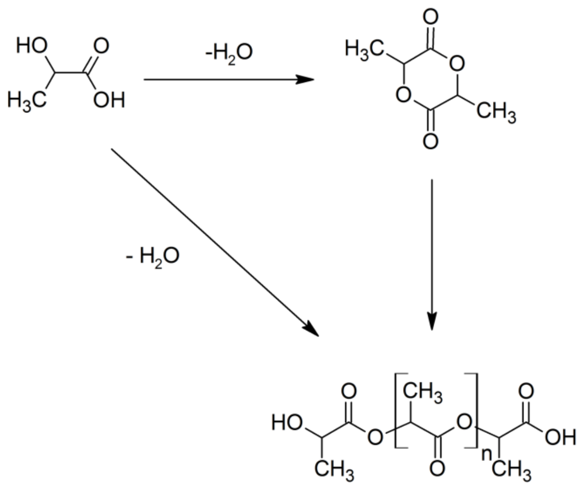
Recycled HIPS (rHIPS)**:** High Impact Polystyrene (HIPS) is often used as a support material in dual-extrusion 3D printing setups. Its soluble nature in d-Limonene allows for easy removal of support structures. Using recycled HIPS for support structures contributes to reducing waste and promoting sustainability in 3D printing processes.

The choice of recycled plastic for 3D printing depends on the specific requirements of the project. When selecting a recycled plastic for 3D printing, consider factors such as material properties (strength, flexibility, temperature resistance), printing ease, compatibility with your 3D printer, intended application, and sustainability goals. It's also important to ensure that the recycled plastic is properly processed and tested to meet quality standards for consistent printing results.

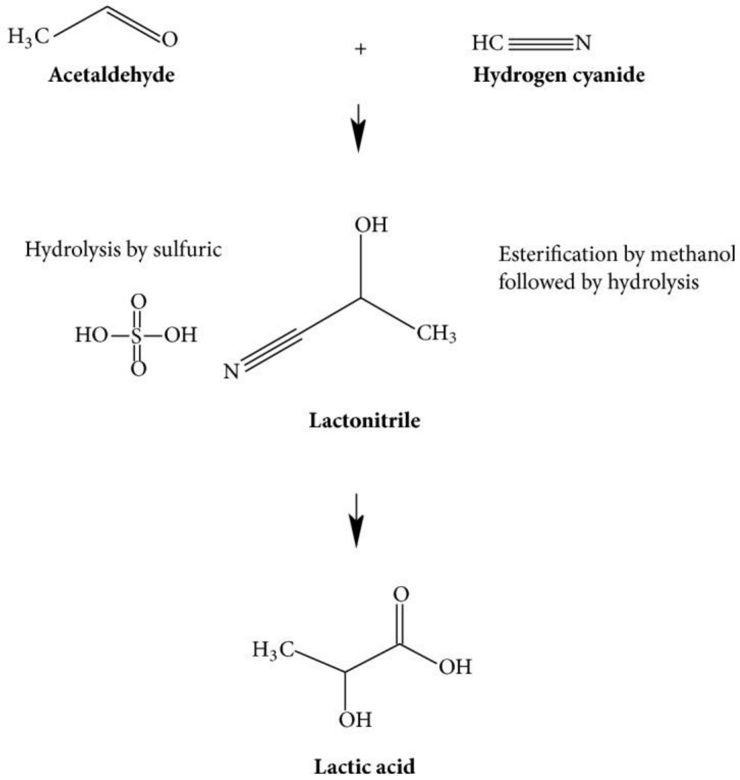
This paper explores the utilization of Polylactic Acid (PLA) among various potential recycled plastics in the context of a project conducted at Cooper Union. The project involved the integration of PLA with CAD and 3D printing technologies.

Polylactic Acid (PLA)

Polylactic acid, also known as poly(lactic acid) or polylactide(PLA), is a thermoplastic polyester with backbone formula $(C_3H_4O_2)_n$ or $[–C(CH_3)HC(=O)O–]_n$, formally obtained by condensation of lactic acid $C(CH_3)(OH)HCOOH$ with loss of water (hence its name). It can also be prepared by ring-opening polymerization of lactide $[–C(CH_3)HC(=O)O–]_2$, the cyclic dimer of the basic repeating unit.



Polylactic Acid (PLA) is a biodegradable and bio-based polymer widely used in various applications, including 3D printing. The manufacturing process of PLA involves several steps, starting from the preparation of raw materials to the formation of the final product.



The process begins by extracting starch from crops such as corn or sugarcane. This starch is then hydrolyzed into glucose molecules. Specific bacteria strains like Lactobacillus or Bacillus are used to ferment these glucose molecules, converting them into lactic acid through biochemical reactions.
After fermentation, the lactic acid solution undergoes purification to remove impurities and unwanted by-products. Techniques such as filtration and distillation are commonly employed to obtain high-purity lactic acid.

The purified lactic acid is then polymerized to form PLA chains. There are two main methods for polymerizing lactic acid: direct condensation and ring-opening polymerization. In direct condensation, lactic acid molecules are heated under vacuum conditions, resulting in the formation of lactide monomers with water as a by-product. These lactide monomers obtained from direct condensation undergo ring-opening polymerization in the presence of catalysts like tin octoate or zinc lactate. This reaction opens their cyclic structure and links them together, forming PLA chains.

Once PLA is formed, it can be processed into various forms such as pellets or filaments suitable for different applications like 3D printing or packaging materials.

Figure 1. PLA printing filament

Figure 2. PLA medical screws

It's important to note that variations in the manufacturing process may occur based on factors such as desired properties of PLA (e.g., molecular weight), specific production technologies employed by manufacturers, and quality control measures implemented at each stage.

Overall, the manufacturing process of Polylactic Acid involves converting renewable resources into lactic acid through fermentation and subsequently polymerizing it into PLA chains using either direct condensation or ring-opening polymerization methods. This sustainable approach aligns with environmental concerns while providing a versatile material for diverse applications in industries like 3D printing.

CAD and 3D Printing Technology: Transforming Recycling with Innovation

CAD (Computer-Aided Design) and 3D printing technologies have revolutionized the manufacturing industry, offering new possibilities for utilizing recycled plastics in sustainable ways. By combining these advanced tools with recycled materials, we can promote resource conservation, waste reduction, and the creation of functional products with reduced environmental impact.

CAD technology plays a crucial role in the process by enabling precise design specifications. Designers can use CAD software to create intricate 3D models that serve as blueprints for the desired product. This digital representation allows for precise measurements, complex geometries, and customization options. With CAD software, designers have greater control over the final product's shape, size, and functionality.

Once the design is finalized using CAD software, it can be translated into a format compatible with 3D printers. The use of recycled plastics in 3D printing offers several advantages:

Waste Reduction: Recycling plastic waste into filament or resin suitable for 3D printing reduces reliance on virgin plastic materials derived from fossil fuels. It helps divert plastic waste from landfills or incineration facilities and gives it a new life as a valuable resource.

Material Efficiency: Additive manufacturing techniques like 3D printing enable more efficient material usage compared to traditional subtractive manufacturing methods. Rather than removing excess material from a larger block or sheet, 3D printers build objects layer by layer using only the necessary amount of recycled plastic material.

Customization: With CAD and 3D printing technologies, it becomes easier to create customized products tailored to specific needs or preferences. Recycled plastics can be used to produce unique designs that meet individual requirements while reducing environmental impact.

Complex Geometries: 3D printing allows for the creation of intricate shapes and complex geometries that may be challenging or even impossible to achieve through traditional manufacturing methods. This opens up opportunities for innovative designs that maximize functionality while minimizing material usage.

Localized Production: The decentralized nature of 3D printing enables localized production close to the point of need. This reduces transportation costs and carbon emissions associated with long-distance shipping since products can be printed on-site or within local communities using recycled plastics readily available in those areas.

When utilizing recycled plastics in CAD and 3D printing, it is crucial to consider certain factors. First, recycled plastics may possess different properties compared to virgin materials due to contamination levels or degradation during the recycling process. It is essential to understand these variations in order to design products that meet the required performance standards. Additionally, proper disposal practices must be followed for recycled plastics at the end of their useful life cycle. This involves implementing recycling programs or appropriate waste management systems to ensure that these materials are responsibly handled and do not contribute to environmental pollution. By addressing these considerations, we can maximize the benefits of using recycled plastics in CAD and 3D printing while minimizing any potential drawbacks.

In conclusion, combining CAD technology with 3D printing offers significant potential for utilizing recycled plastics effectively while promoting sustainability goals such as waste reduction and resource conservation. By harnessing these advanced tools alongside recycled materials, we can contribute towards creating a circular economy where discarded plastic is transformed into valuable resources through innovative design solutions enabled by CAD software and realized through additive manufacturing techniques like 3D printing. This approach not only minimizes environmental impact but also encourages creativity, customization, and localized production within communities, ultimately driving us closer towards a more sustainable future

Research Project at Cooper Union

During the summer of 2023, I had the opportunity to participate in the Cooper Union Summer STEM program. Over the course of three weeks, I enrolled in an intensive course titled "Redesigning Plastic Recycling," which focused on CAD(Computer-Aided Design)**,** 3D printing, polylactic acid (PLA), and the innovative repurposing of plastics**.**

During the first week, our class learned about the various different equipment that we would be using during the class. The equipment that we used were a shredder, a sheet press, an online CADing website called Onshape, and a laser engraver. All of these pieces of equipment would be useful for our project.

The initial week of the program was dedicated to acquainting ourselves with the range of equipment integral to our projects. These included a modified paper shredder capable of handling plastic materials, a sheet press designed to melt and flatten plastic into sheets, an online CAD platform called Onshape, and a laser engraver for cutting, engraving, or marking designs.

The modified shredder featured an enlarged gap specifically tailored for accommodating larger pieces of plastic. This adaptation allowed us to effectively shred plastic waste. The sheet press was equipped with a heated base capable of reaching temperatures up to 450 degrees Fahrenheit. This intense heat enabled us to melt plastic materials before applying pressure for approximately 500 seconds in order to flatten them into sheets.
Utilizing Onshape's web-based CAD software proved invaluable for designing our projects. It provided us with the necessary tools to create intricate designs that could later be translated into printable files suitable for both 3D printers and laser engravers.

The laser engraver itself was a sizable container housing a laser capable of cutting through materials or creating precise engravings or markings. However, it required compatible designs originating from CAD software in order for the machine to accurately interpret and execute them.
During the course, we also gained insights into the type of plastic we would be utilizing: polylactic acid, commonly known as PLA, as discussed earlier.

During the second and third weeks, my group was tasked with creating a clock using misprinted 3D prints that would have otherwise ended up in a landfill. Our goal was to complete the clock face within a tight timeframe and with limited resources for crafting the gears and clock hands. After thoughtful discussions with team members, we determined that our approach would involve shredding the plastics, followed by melting and molding the ground plastic into a single flat plate using a sheet press. However, due to uncertainty about the quantity of plastic required for grinding, we opted to conduct tests using various measurements.

By experimenting with varying quantities of shredded plastic during these preliminary tests, we aimed to determine an optimal amount that would yield satisfactory results while minimizing waste. This iterative approach allowed us to fine-tune our methodology before proceeding with the final production phase.

Figure 3. Shredded PLA from misprinted 3D prints

Refinement of Approach and Design Implementation

Our initial experimentation commenced with a test involving 250 grams of finely ground PLA. This preliminary trial encompassed the shredding of the PLA to create a granulated texture, followed by its placement within the sheet press. However, upon the completion of this process, the resultant sheet exhibited an undesired thickness, along with the presence of numerous lumps. Recognizing the need for adjustment, we deduced that the quantity of PLA utilized might have been excessive. Subsequently, we proceeded to repeat the procedure with 200 grams of PLA. The outcome proved more favorable, yielding a smoother and flatter sheet that met our criteria. Hence, 200 grams emerged as our designated quantity for the final product. With a collaborative selection of colors and precision measurements utilizing measuring cups, we achieved consistently high-quality sheets that formed the foundation for subsequent cutting and engraving endeavors.

Figure 4. PLA filament for use in 3D printing

The second part of the project involved creating a CAD design of the clock using Onshape. Initially, we deliberated on how to design the clock's tick marks, numbers, and overall appearance. We began with a basic nine-inch circle and determined that we would only include the primary clock numbers: three, six, nine, and twelve. To conserve space and simplify the design, we added tick marks for the remaining numbers in a non-sequential arrangement. Lastly, we incorporated smaller tick marks closer to the center of the circle to represent the minutes, ensuring better visibility.

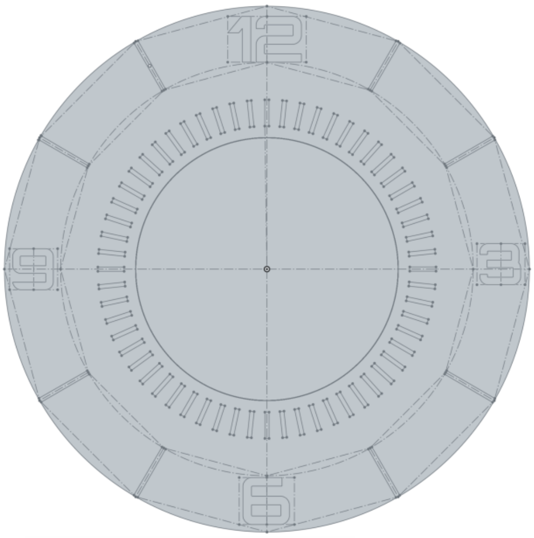


Figure 5. Clock design made using Onshape

Next, we forwarded the CAD file to the laser engraver for cutting the sheets. Instead of engraving, we opted for a complete cut through the sheet since engravings on the plastic sheet were difficult to discern. However, the cuts on the sheet were challenging to perceive, prompting us to add a layer of acrylic plastic behind the plastic sheet to enhance visibility and make it more distinct.


Figure 6. Recycled sheet inside laser engraver

Lastly, the final component we needed to incorporate was the clock hands. To do this, we placed an online order for clock parts to ensure a proper fit when they arrived. We positioned the gears on the back of the clock, situated behind the acrylic, and then installed the clock hands in front of the sheet for clear visibility. Each of us selected a hand color that complemented the overall color scheme of our clocks, enhancing the visual appeal.

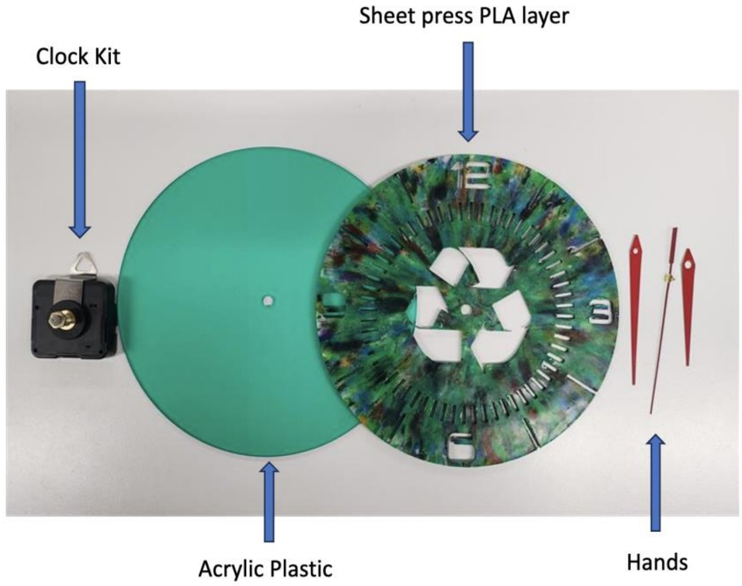


Figure 7 . Components of the clock

Figure 8. Final product of recycled clock

II. Conclusion

This meticulous process not only epitomized our commitment to crafting functional and aesthetically pleasing clocks but also exemplified the synergy between innovative technologies and thoughtful design considerations. This project showcased how innovative technologies like CAD and 3D printing can be harnessed alongside sustainable practices in recycling, fostering sustainability and environmental consciousness. This experience has not only broadened our horizons but also deepened our passion for environmentally responsible and creatively inspired engineering solutions. Our commitment to creating functional clocks while repurposing misprinted 3D prints demonstrates our dedication to reducing waste while embracing cutting-edge technologies. As we move forward, armed with a valuable skill set in CAD technology integration with recycled plastics, we are poised to contribute towards a more environmentally conscious future by redefining what is possible in recycling practices and sustainable engineering solutions.

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