Making Recycled Plastic Bricks with Optimized Accessibility

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Executive Summary

In this project, we designed an accessible plastic recycling system that uses scraps of plastics #1, 2, 4, and 5 to create building bricks. We found that bricks containing a combination of plastics #1, 2, 4, and 5 are able to support more than 5000 N of compressive force (5000 N was the maximum limit of the machine), and an ultimate tensile strength up to about 37 MPa. The high structural strength, accessibility, and sustainability in creating these recycled plastic bricks make them an attractive building block option for a variety of small-scale structural projects.

Introduction

One of the most daunting issues facing the environment is overproduction and poor management of waste. Industrialized nations like the U.S. produce large amounts of municipal, commercial, and industrial waste. The average American produces 4.9 pounds of waste per day, one of the highest rates among industrialized nations.[1] The overproduction of waste has many negative environmental and health impacts. Hazardous waste can contaminate land, water, and air, which directly impacts the health of people and ecosystems that live nearby waste sites. Landfills are large producers of methane, a potent greenhouse gas, which contributes to climate change.[2] Additionally, the space that landfills require (on average, about 600 acres per landfill), means that large amounts of wildlife habitat are destroyed in order to house waste. Landfills also have tremendous social and economic impacts. On average, large landfills decrease the value of the land around it by 12.9%. Additionally, low-income and minority communities are more likely to live near landfills and feel the negative impacts of these waste sites.

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1 https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#:~:text=The%20Current%20National%20Picture,-EPA%20began%20collecting&text=The%20total%20generation%20of%20municipal,25%20million%20tons%20were%20composted.

2 https://www.colorado.edu/ecenter/2021/04/15/hidden-damage-landfills#:~:text=Large%20landfills%2C%20on%20average%2C%20decrease,bugs%2C%20and%20water%20supply%20contamination.

Of the "landfilled" plastic waste, much of it ends up in the ocean – plastics make up about 80% of all marine debris.[3] Plastic pollution in the ocean harms marine life because animals often mistake the plastic waste as food, can become entangled in plastic waste, etc. This plastic pollution also disrupts food supply and health. For example, microplastics disrupt animals' biological systems and contaminate our food supply as they can bioaccumulate through the food chain and reach humans through seafood.[4]

One waste management technique that can reroute materials from the landfill is recycling; however, there are many barriers that prevent recycling from actually happening. The majority of recyclable materials do not actually get recycled due to contamination and inefficiency of sorting, which makes recycling a costly process. The economics of recycling also do not support large scale recycling systems – oftentimes, it is cheaper for businesses to obtain virgin materials rather than recycled materials. A material of particular concern is plastic, especially plastics #3-7. Figure 1 shows how plastic waste has been managed from 1960 to 2018. It can be seen that most plastic waste is landfilled, while a miniscule proportion is recycled. This recycled proportion increases very slightly from year to year, or stays stagnant. In 2018, the recycling rate of plastics was 8.7%.[5] Different plastic types have different recycling rates. Plastics #1 and 2 (PET and HDPE) have the highest recycling rates, at 29.1% and 29.3%, respectively, in 2018.[6] Other plastic types, like PVC and LDPE (plastics #3 and 4), have much lower recycling rates, at 1.2% and 1.7%, respectively, in 2018.[7] This discrepancy is due to the fact that different plastic types have different economic and technical efficacies for recycling. For example, thin plastic films and bags can clog recycling machinery. Other plastic types have higher melting temperatures, which makes recycling of those materials more energy intensive and costly.

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[3] https://www.ehn.org/ocean-plastic-pollution-2654378379/how-much-of-ocean-pollution-is-plastic
[4] https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0240792
[5] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data
[6] https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/plastics-material-specific-data
[7] https://www.statista.com/statistics/623553/plastic-bottle-recycling-rates-in-the-us-by-material-type/

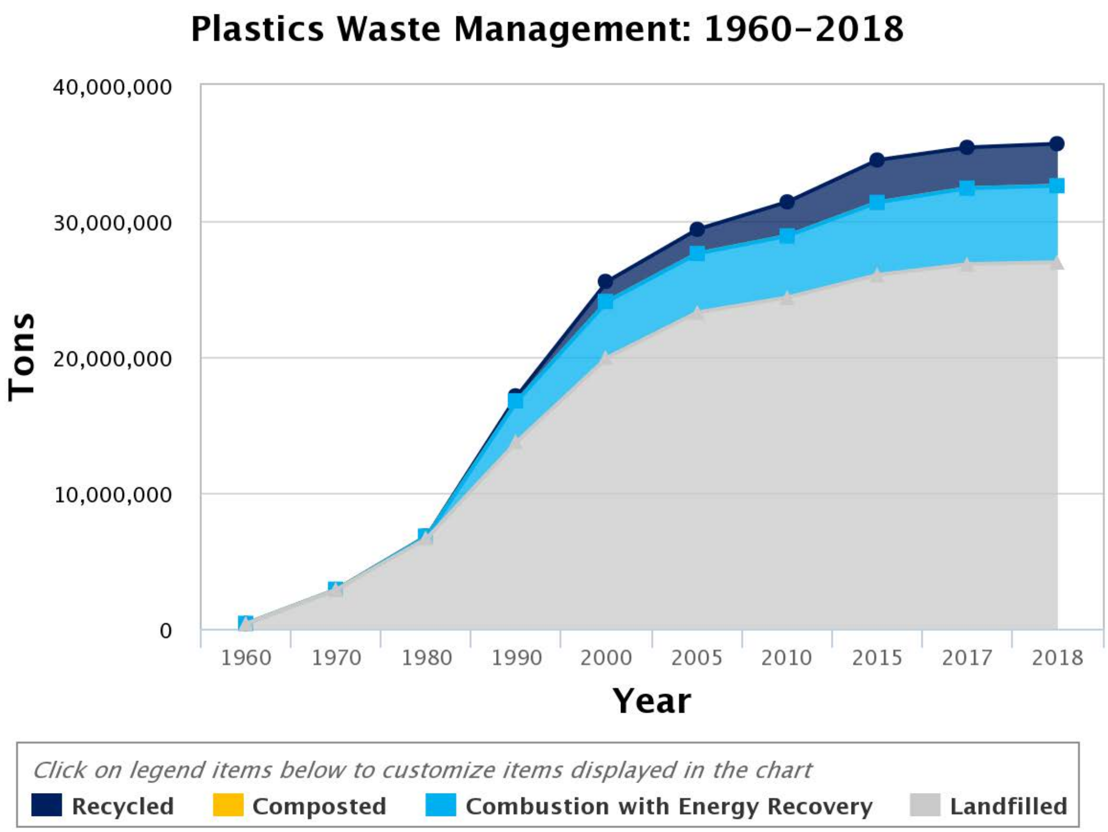

Figure 1. Plastics Waste Management from 1960 to 2018[3]

Technical Design

Our solution to the recycling problem described above is a design of an effective yet simple procedure that describes how to utilize various types of commonly discarded plastics in order to recycle them into dense plastic bricks that can be used for construction, landscaping, and many other purposes. This procedure is meant to be easily accessible to many people, without the need for highly specialized tools and machines, and to produce a product that can be useful for many different applications especially on a college campus like Duke University.

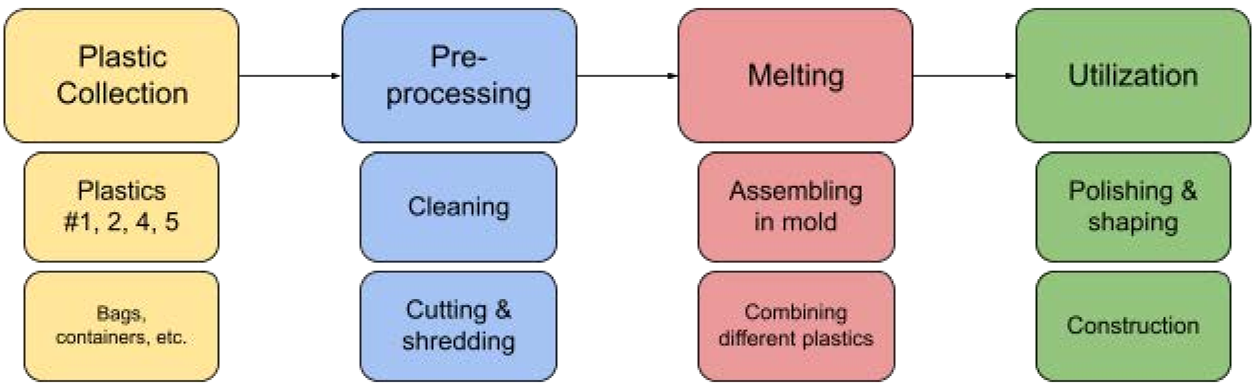

Figure 2: Visual Representation of our recycling process and its various components

Figure 2 above describes the general design procedure. It represents the four main components: Collection, Pre-processing, Melting, and Utilization.

In the collection phase, the main goal is to collect four types of recyclable plastics: #1, 2, 4, and 5. These four plastics are used because they do not emit toxic fumes when heated or melted, and are most accessible in large quantities. These can come in the form of containers – like bottles, jugs, food containers, or even plastic grocery bags that are usually made of plastics #2 or #4. These are very plentiful and easy to find and collect.

The pre-processing phase includes all of the preparation the raw plastic items like the bags and containers must go through before they can be efficiently transformed. First, they must be cleaned of any other non plastic substances before they can be utilized. This includes things like food, liquids, container wrappers or labels, etc. Once the plastic is isolated, it can go to the next step of cutting down and shredding. It was too hard and inconsistent to melt down the giant jugs, bottles, and containers before breaking them down to smaller components, and this could lead to burning the plastics which releases toxic fumes and needs to be avoided at all costs. There are many different methods to break down the individual plastic items. Some of the methods that were ultimately chosen after testing based on their simplicity and effectiveness were scissors, a paper cutter, and a shredder. Scissors were used to roughly cut big items like jugs or bottles into flatter components, which could then be fed into a simple credit card shredder in order to really cut it down into small inch length rectangles (as seen in Figure 5 in Appendix) which are much easier to place into the mold and melt evenly. The paper cutter (Figure 8 in Appendix) was especially useful for bags in order to cut them down into similarly sized pieces, as the bags would get stuck in the credit card shredder (as seen in Figure 6 in Appendix). Using the combination of these three items, almost all #1, 2, 4, and 5 plastic items can easily be broken down with relatively little human exertion. A more automated system could probably be developed if there was a larger scale recycling operation, but for the scale of this project this mixture of simple tools and human effort proved to be the most cost effective and simple procedure to process the plastic to prepare for the melting step.

The melting step consists of placing the processed plastic into a mold, and then applying heat to it in order to melt it down to create a condensed brick or shape that then can be used for a different purpose. Different molds can be used depending on the desired application of the plastic product. For the purposes of this project, a rectangular mold was used, where the final shape was that of a simple rectangular bread pan. This was selected because of its already simple “brick-like” shape, and the fact that it is a cheap version of a mold material that can be subjected safely to high heats. Once the mold is obtained, the plastic can be put into it. With this step, there are a number of different considerations to keep in mind. First, it is beneficial to ensure that the plastic is processed correctly, and there aren’t any large uneven chunks of plastic which might lead to an inconsistent mix. Second, different types of plastic can be mixed evenly in the mold to create a composite mix (more details in the Technical Section below). Third, before melting, the plastic should be compressed within the mold as much as possible. This can be done efficiently by applying weight to the top of the plastic in the mold. In this project, this was done by putting another bread pan with heat resistant weights inside in order to compress the plastic inside the mold to ensure faster and more even heating of the plastic. The two bread pans were lined with parchment paper to prevent the plastic from sticking (as seen in Figure 9 in Appendix). Once all of these factors are taken into account, and the plastic is appropriately placed into the mold, the actual heating can take place.

The heating step can be done in different ways, yet the simplest and most efficient way that was determined was to use a simple toaster oven. At first, a hot plate was used (as seen in Figure 7 in Appendix), yet this method took too long to transfer heat to the plastic, and only applied heat from one direction, leading to an uneven melting process. The toaster oven was cheap, large enough enough to put the selected molds into, and could produce temperatures that were high enough for the melting points of the plastics. The plastic in the mold was simply placed into the toaster oven and the temperature was set to a little above the melting point of the plastic in order to ensure it reached that temperature. The plastic was left in the heated toaster oven for 5-10 minutes at a time, checking periodically to ensure that it was melting correctly and then taken out when the plastic was finished melting. The mold was then left to cool in the air for 10 minutes and then washed with room temperature water to ensure that it was cool enough to handle, where it was then taken out of the mold. The brick has now been completed (a completed brick can be seen in Figure 10 in Appendix).

Safety notice: There are a number of potentially dangerous components to this process if not performed with the appropriate level of protection and caution. Firstly, the processing step requires care and vigilance with sharp tools such as scissors, cutters, and paper guillotines. Second, the melting of plastic may produce toxic fumes and chemicals that are harmful for people to breathe in. This usually only happens when plastic burns, not melts, but especially when testing the precise temperatures, it can be difficult to walk the fine line. To ensure safety, The melting step was all done inside a fumigation hood so that nobody was exposed to any potential toxic products from the melting of plastic.

The utilization step is perhaps the most important step in our recycling process as it details what and how this now recycled plastic can actually be used for, therefore completing the recycling process. More information on the utilization of the bricks can be found below in the Commercialization and Business Plan sections.

Testing

The bricks created were tested in various ways to determine certain physical characteristics that could be useful in determining their application in certain structural contexts. The Ametek-Lloyd LRX Plus machine (as seen in Figure 11 in Appendix) that was readily available to test allowed the testing of compressive strength and flexural strength. The compressive test that was performed was somewhat limited because the machine only had a max compressive load of 5 kN which all the bricks were able to withstand. The data collected from this test is seen in Figure 3. A flexural test was also performed, which consisted of a 3-point-bend test with center loading. The results from this test are seen in Figure 4.

The strength of 4 completed bricks, each comprised of varying amounts of plastics # 1, 2, 4, and 5, were evaluated with a compression test and a 3-point-bend test. Brick 1 (Figure 12 in Appendix) was a non-uniform block containing all four plastics but comprised mostly of #1 and 2, with a total weight of 210 g. Brick 2 (Figure 13 in Appendix) was a smaller uniform block containing 12.5 g of each plastic, with a total weight of 49 g. Brick 3 (Figure 14 in Appendix) contained only plastics #1 and #2, with a total weight of 48 g. Brick 4 (Figure 10 and 15 in Appendix) contained 36% of plastic #1, 6% of plastic #2, 10% of plastic #4, and 48% of plastic #5, with a total weight of 225 g.The details of each brick can be seen clearly in Table 1 below.

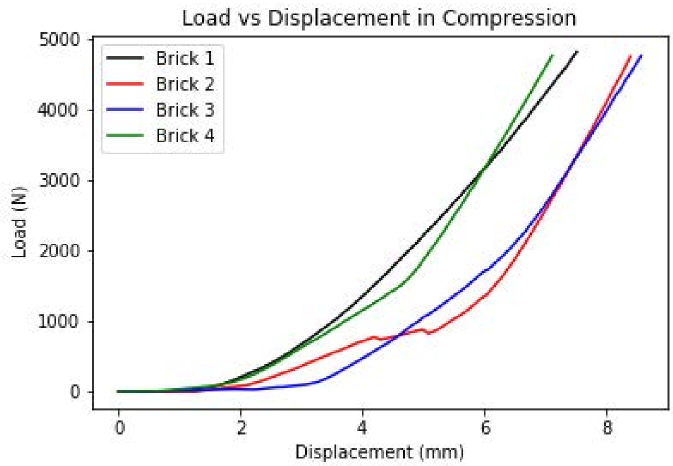

Figure 3. The Compressive Strengths of 4 Plastic Bricks from a Compression Test

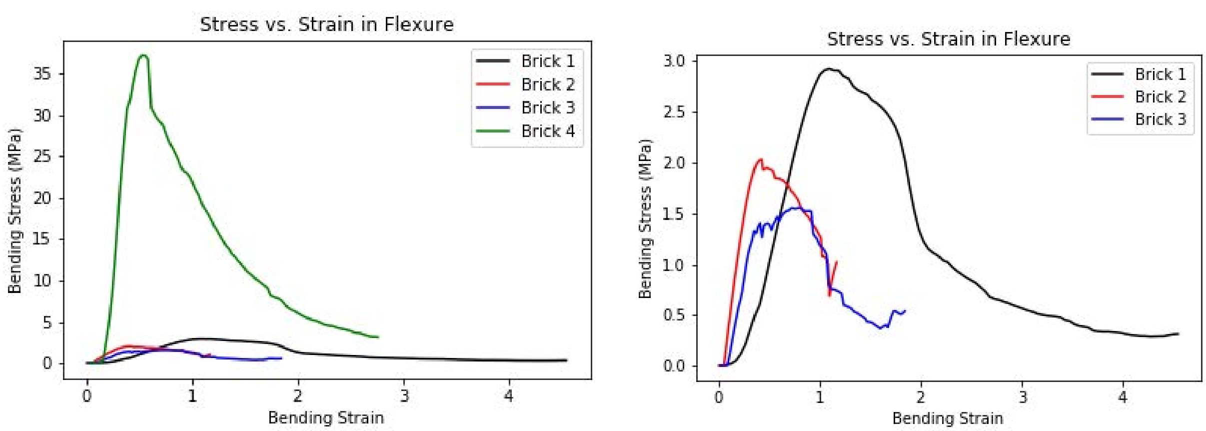

Figure 4. Left: Tensile Strengths of 4 Plastic Bricks from a 3-Point-Bend Test.
Right: Tensile Strengths of the First 3 Bricks Isolated to be More Easily Seen.

Brick	Dimensions l x w x h (in)	Density (g/in^3)	Composition	Ultimate Flexural Strength (MPa)
1 (non-uniform)	8 x 4.5 x 1	5.83	Plastics #1,2,4,5, Mostly #1, 2	2.92
2 (uniform)	4.5 x 3 x .5	7.26	Plastics #1,2,4,5 (25% of each plastic by weight)	2.03
3 (uniform)	4.5 x 3 x .5	7.11	Plastics #1, 2	1.55
4 (uniform)	8 x 4.5 x .5	12.5	Plastics #1,2,4,5, (Mostly #5, 1)	37.19

Table 1. Composition and Ultimate Tensile Strength of Tested Bricks

Environmental and Social Benefit Analysis

In the early stages of research, our team came across the inefficiency of plastic recycling in the United States. The EPA reported that the US only recycled 8.7% of plastics in 2018. Given the 35 million tons of plastic waste generated that year, 32 million tons of plastic was forced to go to energy recovery or a landfill.[8] In many cases, waste does not make it there, and many waste products become direct pollutants. Plastic waste is especially harmful, as it persists in the ecosystem for centuries and can bioaccumulate. This problem also extends to Duke's campus. Walking around campus, our team found that many places on campus were lacking recycling bins while others had become contaminated by the waste of an overflowing trash bin next to it. A waste audit conducted by Duke Student Government in Spring 2021 found that up to 79% of waste in Bryan Center trash cans was missorted, with the average bin being 40-50% missorted.[9] Other waste never makes it into any bins and becomes litter, especially in areas that lack any waste bins at all (like the Blue Zone parking lot). Because of all of these problems, we

[8] https://www.epa.gov/sites/default/files/2021-01/documents/2018_ff_fact_sheet_dec_2020_fnl_508.pdf
[9] https://www.dukechronicle.com/article/2021/09/duke-university-duke-student-government-dsg-waste-audit-services-sustainability-committee-results-recycling

wanted to create a closed-loop system that could turn plastic on campus into something that could be used on campus.

Our solution was creating bricks out of plastic that could be used on campus. We succeeded and made several bricks out of various types of plastic (#1, 2, 4, and 5). One benefit of making these bricks is a reduction of plastic waste. Waste that would usually be sent to a landfill, incinerated, or leached into the environment. Plastic pollution is a major issue that affects many ecosystems, especially our oceans. The Great Pacific Garbage Patch, a swirling gyre of trash between the Continental US and Hawaii, is around twice as large as Texas. It is especially hard to clean-up because it is largely made of microplastics. Microplastics are small bits of plastic that have been found in human blood and the placentas of pregnant women.[10] The Center for Biological Diversity reports that nearly 700 species eat or get caught up in plastic litter, including endangered species like the Hawaiian monk seal and Pacific loggerhead turtle.[11] Communities that are heavily influenced by plastic pollution could use the plastic that litters their rivers, beaches, and oceans to create something new.

Being able to use multiple different types of plastic in a single brick simplifies the sorting process, and allows us to use plastics #4 and 5 which are less likely to be recycled than #1 and #2. We were also able to use different kinds of plastic bags, including grocery bags. These are often hard to process, as they can easily become entangled in machinery. The bricks all ended up using about 200 g of plastic, so assuming that a standard water bottle contains 9 g of plastic, each brick uses roughly 22 bottles. Given that only 21% of recycled PET (#1) plastic is actually processed, only 4-5 of these bottles would have actually been recycled if we placed all 22 into a recycling bin.[7]

We also hoped to be able to create a building material that requires less energy than traditional materials like concrete or bricks fired from clay. The concrete industry is especially massive, making up about 7% of the world's CO2 emissions. If concrete production were a country, it would be the third largest emitter of greenhouse gasses behind the US and China.[12] Making a cubic meter of concrete takes 2775 MJ of energy[13], while the same amount of clay bricks

[10] https://www.theguardian.com/environment/2022/mar/24/microplastics-found-in-human-blood-for-first-time?utm%3C/i%3Esource=Twitter
[11] https://www.biologicaldiversity.org/campaigns/ocean_plastics/
[12] https://phys.org/news/2021-10-concrete-world-3rd-largest-co2.html
[13] https://www.geoplastglobal.com/en/blog/energy-consumption-production-of-concrete/

requires 2524 MJ.[14] Assuming that our plastic bricks took 30 minutes to make in our 1800 W toaster oven, we used 900 Wh (3.24 MJ) of energy to make a brick that is roughly .0005 m^3, therefore the total energy for a cubic meter is 6480 MJ. Although our current brick is not an improvement in terms of energy production, the company ByFusion claims that production of their ByBlock emits 41% fewer greenhouse gas emissions than concrete.[15] This makes us confident that scaling up this process is not only possible but much more effective. Making our bricks on campus is also beneficial because it did not require any transportation of heavy materials, and it used plastic waste, an extremely available resource.

Production of concrete and other bricks requires materials such as clay and limestone that need to be acquired from somewhere. Limestone mining to produce concrete causes a lot of environmental problems including habitat loss and noise and dust pollution. It also has impacts on communities by affecting supplies of groundwater and creating underground cavities that can cause sinkholes.[16] This acquisition of these raw materials also requires a lot of heavy machinery for mining, processing, transportation, etc. Alternatively, the plastic that we used is freely available on campus and requires minimal transportation and processing of lightweight materials.

Our group's original decision to make recycled bricks as opposed to building out recycling infrastructure and education on campus was the right choice for a number of reasons. First, there are direct environmental benefits to a closed-loop recycling system, including reducing plastic pollution and possible savings on greenhouse gas emissions. There are also indirect effects, such as reducing the need for limestone mining and transportation of heavy materials. Finally, there is a social benefit that could be gained from using these bricks on campus. We believe that if Duke students saw things on campus made from recycled plastic, they would be more inspired to properly recycle. A main problem that recycling faces in the United States is apathy. Many Americans think, "it all goes to the same place," or simply do not understand just how much waste they produce as well as the negative effects their waste could have. Perhaps if people see their recycled products being put to good use right here on campus, they would realize the difference they can make by simply taking an extra five seconds to sort waste correctly and avoid recycling contaminated goods.

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[14] https://www.irbnet.de/daten/iconda/CIB4274.pdf
[15] https://www.byfusion.com/byblock/
[16] https://www.researchgate.net/publication/339304868_Environmental_Hazards_of_Limestone_Mining_and_Adaptive_Practices_for_Environment_Management_Plan

Commercialization and Preliminary Business Plan

The Global Building Materials Market size was estimated at USD 271.98 billion in 2020, is expected to reach USD 286.23 billion in 2021, and projected to grow at a CAGR of 5.57% reaching USD 376.72 billion by 2026.[17] Our recycled plastic bricks will be able to fill a small but significant niche within the global landscape.

Our product has been preceded by some previous similar practice attempts. *ByFusion*[18] is a company that uses a combination of steam and compression to form different types of plastic into standardized 16-by-8-by-8-inch plastic bricks, with target downstream use including fences and retaining walls to public terraces and bus stops. There have been attempts in using recycled plastic to construct one story building structures, with notable efforts including *Plásticos (Plastic Concepts)*[19], a startup in Cundinamarca, Colombia. The company uses an extrusion process, as the plastic discarded mainly from recyclers and factories is melted and emptied into a final mold, creating a three-kilo brick (6.6 lbs), which is further used in residential housing construction with a traditional building method; *Recycled Living*[20] is a non-profit organization located in Portland, Oregon, where the waste plastic is turned into building bricks through a shredding-heating-compression process, where the bricks are intended to be used to build small houses for the homeless community in Portland. Another end use functionality is explored *bygjenge makers ltd*[21], a company based in Kenya that turns discarded plastic into paving stones, where the waste plastic is mixed with sand and molded into paving bricks.

Referencing previous attempts, the concept of Duke team can be employed in similar downstream markets of building bricks for simple structures. Zooming into the brick's

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17 https://www.globenewswire.com/news-release/2021/10/29/2323637/28124/en/Global-Building-Materials-Market-Research-Report-2021-to-2026-by-Structure-Application-and-Region.html

18 https://www.fastcompany.com/90714272/this-startup-is-turning-non-recyclable-plastic-into-building-blocks-fit-for-construction

19 https://www.archdaily.com/869926/this-house-was-built-in-5-days-using-recycled-plastic-bricks

20 https://pamplinmedia.com/pt/9-news/522442-417260-portland-student-recycles-plastic-into-bricks-for-homeless-huts

21 https://www.designboom.com/technology/gjenge-makers-recycled-plastic-bricks-kenya-02-08-2021/

application on Duke's campus, the bricks can be designed for functions including supporting pallets for tenting or outdoor performance events, outdoor supporting structures like benches at bus stops, or decorative structures.

The recycled plastic bricks hold unique projected advantages when employed in the market deriving from both the physical property of plastic and the nature of the recycling workstream. When used for resident housing materials, the plastic bricks inherently insulates heat better than traditional materials including concrete. The bricks can further be designed to be hollow to employ the trapped air to improve insulation capability. Additives can be added to the bricks to retard combustions. The plastic bricks are also more earthquake-resistant. When used as a supporting material, it is reported that plastic bricks have better supporting strength than its traditional counterparts. At last, the circular economy feature of the product will add its appeal for environmental conscious institutions and individuals.

The projected industrial manufacture process for recycled plastic bricks is drastically different from the traditional building materials construction as well, with great cost saving potentials both in raw material and transportation. The raw material, waste plastic, can be collected through avenues like industrial sources, recycling plants, or an organized residential recycling system at a free price, if not compensated for waste processing. Furthermore, at an earlier stage because of the local scale of the operation the potential proximity between the source of raw material and end use sites eliminates the cost for long industrial transportation processes.

In the next 'Business Plan' section, we will further dive into the specific cost economics of the current brick manufacture process and an analysis of execution in the current business space.

Business Plan

The materials used for the final prototype were: two stackable bread pans (total of $3.96)[22], a guillotine paper cutter ($29.99)[23], a credit card shredder ($34.94)[24], and a toaster oven ($179.95)[25]. The total cost for these materials was $248.84. The average time needed to create one brick was about 90 minutes, with 30 minutes for shredding the plastic and 1 hour for melting in the toaster oven.

Initially, instead of a toaster, a Filastruder (which costs $309.99 with a nozzle that costs $24.95) was going to be used for melting/extruding the plastic. However, in order to use the Filastruder, the plastic would have to be shredded into 3 mm sized pellets to fit in the nozzle. This would require a more advanced shredding machine, which could cost up to thousands of dollars. Additionally, the plastic would have to be cleaner and better sorted to ensure that it doesn't clog up the machine. Overall, the Filastruder would make the process less practical at the smaller scale we were aiming to work at. However, at a larger scale, such as the Precious Plastic Project, the kit for creating bricks costs about $10,200. While this is a pretty high cost, bricks could be created faster and more efficiently, which could allow for larger mass sales and profits.

If these plastic bricks were sold, they would compete with clay bricks and concrete bricks. Clay bricks can cost about $0.35 to $0.90 per brick (usually closer to $0.90) depending on the material and type of brick. Concrete bricks are cheaper and can be about $0.20 per brick. A pallet of clay or concrete bricks, which consists of 400-525 bricks, can cost $140 to $470 per pallet, once again depending on the material and type of brick.[26]

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https://www.walmart.com/ip/Mainstays-Nonstick-8-4-x-4-4-x-2-4-Loaf-Pan-Meatloaf-and-Bread-Pan-Dark-Gray/296288763?wl13=1191&selectedSellerId=0

23
https://www.walmart.com/ip/12-Paper-Cutter-A4-To-B7-Metal-Base-Guillotine-Page-Trimmer-Blade-Scrap-Booking-for-Office-Home-School/924817096?wmlspartner=wlpa&selectedSellerId=101080551

24
https://www.amazon.com/AmazonBasics-8-Sheet-Cross-Cut-Credit-Shredder/dp/B00YFTHJ9C/ref=sr_1_3?crid=38CBFUV1GOEH9&keywords=credit+card+shredder&qid=1643669870&s=home-garden&sprefix=credit+card+shredder%2Cgarden%2C111&sr=1-3

25
https://www.amazon.com/dp/B01M65AOK1?th=1&linkCode=ll1&tag=%2Bkitchen-gearoid-20&linkId=2aa44c9fb1ffdad01191800033da37bf&language=en_US&ref_=as_li_ss_tl

26 https://homeguide.com/costs/brick-prices

It is likely that plastic bricks would be sold at a slightly higher price than regular clay or concrete bricks. It is very difficult to find recycled plastic bricks currently being sold on the internet, but one recycled plastic brick was being sold on Etsy for $35,[27] while 40 ft of non-recycled plastic bricks were being sold for $79.37.[28] However, to make plastic bricks competitive compared to regular clay and concrete bricks, the bricks could be sold for as low as $1, meaning that about 250 bricks would have to be sold to get any profit (based on material cost and not including labor costs).

Plastic bricks can be valued higher (and sold at higher prices) than clay or concrete bricks because they can be thinner, lighter, have heat insulating properties five times greater than standard bricks, are highly effective at insulating noise, and are better for earthquake zones and fences due to the material's general flexibility which can absorb abrupt shock loads. Additionally, plastic bricks' compressive strength can be greater than concrete bricks.[29] The compression test conducted on the plastic bricks created for this project concluded that the bricks could all support more than 5000 N of compressive force – the machine was not able to exert more force to test the limits of the bricks. However, other projects have found that plastic bricks cannot be used like standard bricks as they have been found to compress under heavy structural loads. The plastic bricks have instead been used for wall fillers, non-load-bearing walls, retaining walls, and soundproofing walls.[30] Nevertheless, it should be noted that most of the "plastic bricks" referred to in previous projects are lower fidelity or contain different materials and plastics than those used in this project. Some of the "plastic bricks," or Ecobricks, were created by filling #1 or #2 plastic bottles with sand or other types of plastic (such as plastic bags).[31] The bricks from this project were further tested using a 3-Point-Bend Test, which concluded that the bricks had an ultimate flexural strength of 2-37 MPa (depending on the concentrations of different plastics and melting methods as seen in Table 1 above). The 2 MPa bricks compare to concrete bricks, which have a modulus of rupture or flexural strength of about

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27 https://www.etsy.com/listing/1150920203/plastic-brick-100-recycled-from-plastic?gpla=1&gao=1&

28 https://www.homedepot.com/p/Argee-40-ft-Decorative-Plastic-Brick-Edging-with-6-Solar-Lighted-Bricks-RG840S/202079520?source=shoppingads&locale=en-US

29 https://www.google.com/url?q=https://medcraveonline.com/MOJCE/MOJCE-03-00082&sa=D&source=docs&ust=1649131494150012&usg=AOvVaw3170uXenrx1UHmOsRZYEDF

30 https://www.expertskiphire.co.uk/plastic-bricks#:~:text=One%20of%20the%20drawbacks%20of,they%20make%20superb%20wall%20fillers

31 https://www.buildwithrise.com/stories/ecobricks-an-answer-to-plastic-waste

3-4 MPa. Especially because these plastic bricks were not perfectly formed and still had imperfections and various air bubbles inside the plastic bricks, which would naturally lead to a weaker brick especially in flexure. Concrete bricks are stronger than regular bricks, which typically have a flexural strength of about 2 MPa. Therefore, the plastic brick with a flexural strength of 37 MPa far exceeds conventional concrete bricks, giving such bricks a great competitive advantage. Further testing should be done on recycled plastic bricks to determine their effectiveness under heavy structural loads.

One possible disadvantage to plastic bricks is the lack of knowledge about the effects of extended environmental exposure. It is possible that plastic could break down with high exposure to the sun, interactions with other materials such as cement (which has a high pH), and methane from food contaminants if the plastic is not properly cleaned, but these effects need to be researched more thoroughly. However, it is known that plastics can be highly flammable, and it is possible that certain plastics can release toxic gasses such as dioxins, furans, mercury, and polychlorinated biphenyls into the atmosphere. [32] While #3, #6, and #7 plastics can release toxic gasses when melted, the other plastics, which were used in this project (PE and PP plastics), are safer, but can still be dangerous when they are burned as they can release VOCs (volatile organic compounds). [33] This danger can be avoided by being careful in the melting process, but also by using fire retardants. While the fire retardants are effective, they can make the material less workable. While it has been said that plastic should not be used for building because of leaching of microplastics and other toxins, it has been found through research that this information is false, and that there is very little leaching compared to alternative materials such as treated wood. [34] A consumer can weigh the pros and cons of plastic bricks compared to other materials, but there is also a lot of misinformation or lack of information about plastics in construction. However, considering the available information and data, plastic bricks can certainly compete with clay and concrete bricks in terms of material value and effectiveness.

[32] https://phys.org/news/2019-07-ecobricks-plastic-pollution.html
[33] https://onearmy.github.io/academy/plastic/safety
[34] https://www.greenbuildermedia.com/blog/the-promise-and-pitfalls-of-plastics-in-construction

Plastic crediting[35], plastic offsetting[36], market incentives[37], and special government funding through business grants for recycling plants[38] will certainly support the production of plastic bricks and contribute to profits. Additionally, clay fired bricks have been found to be problematic in that the brick kilns emit air pollutants that result in greenhouse gas emissions, CO_2 emissions, and black carbon emissions that significantly contribute to global warming.[39] With developing efforts to cut down on carbon emissions and other practices that negatively affect the environment, it is possible that the price of conventional bricks could increase in the near future (with government imposed market incentives or fees/taxes). With sustainable government initiatives, it is therefore possible that conventional bricks could become more expensive while plastic bricks become less expensive, which would result in a higher demand for plastic bricks.

Even without government imposed incentives or support, the positive sustainable influence of plastic bricks (especially compared to carbon emitting clay bricks) will certainly be attractive for public institutions, such as universities, that have made commitments to sustainable practices or net-zero carbon goals. It is therefore likely that such institutions would be willing to pay more for recycled plastic bricks.

Overall, the research from this project has shown that it is possible to create recycled plastic bricks at a smaller scale with low cost materials. Although the methods require a lot of time and effort, there is potential to improve the methods and results with further testing on differing concentrations and techniques (to decrease the costs, improve the material strengths, and reduce dangers of emitting toxins). It is also possible to use larger scale methods for more efficient mass production. While the total cost of materials and labor would likely make recycled plastic bricks more expensive than clay and concrete bricks (economic competitors) which are

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35 https://www.fastcompany.com/90613763/plastic-credits-are-the-newest-kind-of-pollution-offset-but-do-they-make-a-difference

36 https://www.preventedoceanplastic.com/plastic-offsetting/

37 https://www.oecd.org/environment/outreach/EN_Policy%20Manual_Creating%20Market%20Incentives%20for%20Greener%20Products_16%20September.pdf

38 https://deq.nc.gov/about/divisions/environmental-assistance-and-customer-service/recycling/data-annual-reports-and-publications

39 https://hablakilns.com/the-brick-industry/key-issues/#:~:text=Air%20pollution%20generated%20by%20brick,including%20black%20carbon%20(soot).

sold at very low prices, recycled plastic bricks could be valued higher for their material benefits (insulating and shock absorption capabilities, high flexural strength and compressive strength potentials), and sustainable benefits (which could be attractive to institutions with sustainable commitments). Additionally, with government action and support, recycled plastic bricks could be made cheaper while competitors are made more expensive. Therefore, we conclude that plastic bricks can certainly be economically competitive.

Conclusions

Through this project, our team learned a lot about the recycling process and the potential for recycled plastic bricks. We gained valuable insight into the difficulties of the recycling process. In particular, we learned why some plastics are worse than others – for example, plastics #3, 6, and 7 are unrecyclable as they emit toxic fumes when heated, and plastic #4 is generally non recyclable as plastic films and bags get tangled in shredding machines. We found that multiple types of plastic can be melted together and used in one brick (#1, 2, 4, 5), which relieves some pressure from sorting waste, which is a big issue that significantly contributes to the non-profitable high cost of recycling. The only issue with mixing plastics is the differing melting points, as burning plastics can emit dangerous toxins. However, this danger can be avoided with careful melting methods and fire retardant additives. Our research can be used to push for the elimination of unrecyclable plastics (#3, 6, 7) and encourage the mass production of recycled products (such as bricks). We have shown that there can be demand for recycled products, as recycled bricks can be economically competitive as a structural material. As a result, our research can motivate people to continue recycling as the recycling process can be profitable. To improve the economic and material value of recycled plastic bricks, further testing should be done on differing percentages of each plastic and their corresponding strengths, and the effects of additives (such as fire retardants) and environment exposure.

Appendix

The Trello used to track the progress and notes of this project can be seen here: https://trello.com/invite/b/Om25GoeE/e4b3d66aa6dbd8f0be77cb6ffbb0c5fa/recycling-infrastructure-education

Figure 5. Plastic #2 Shredded Using the Credit Card Shredder

Figure 6. Plastic #4 Bags Tangled in the Credit Card Shredder

Figure 7. Medium Fidelity Process of Melting Larger Plastic Bricks with a Hotplate

Figure 8. Guillotine Paper Cutter Effectively Shredding #4 Plastic Bags

Figure 9. Final Prototype Plastic Brick in Process of Melting in Bread Pan

Figure 10. Completed Final Prototype for Recycled Plastic Brick (Brick 4)

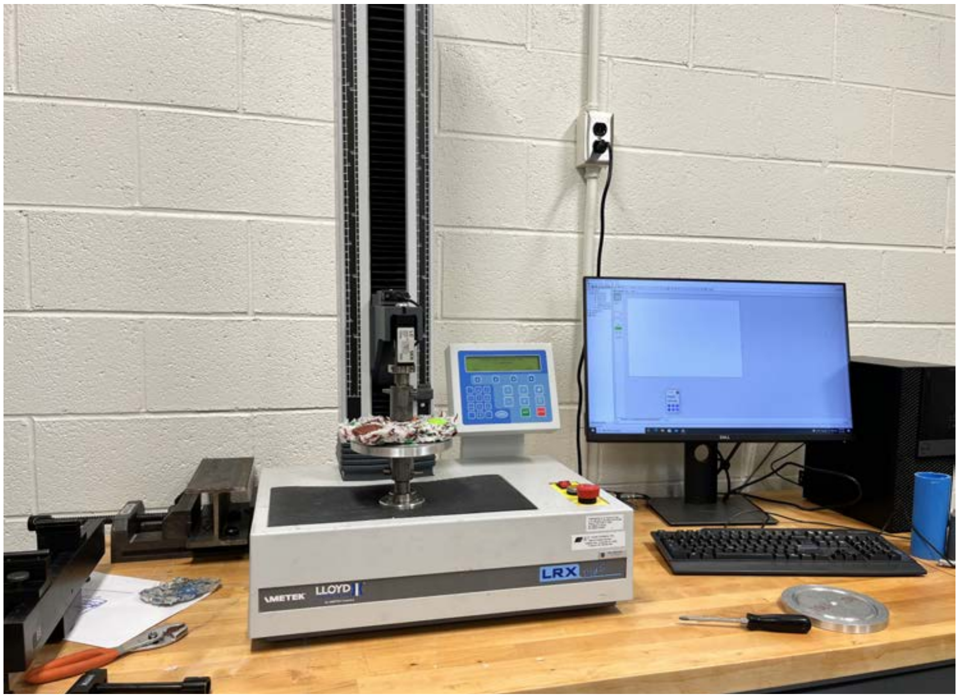

Figure 11. Ametek-Lloyd LRX Plus Machine used to Conduct Compression Test and 3-Point-Bend Test

Figure 12. Brick 1 After 3-Point-Bend Test

Figure 13. Brick 2 After 3-Point-Bend Test

Figure 14. Brick 3 After 3-Point-Bend Test

Figure 15. Brick 4 After 3-Point-Bend Test