Waste Pavilion Project

A Major Qualifying Project Report: Submitted to the Faculty of

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Acknowledgements

The authors would like to thank our advisor Professor Soroush Farzin for his dedicated support and involvement in every facet of our academic journey. From inspiring and motivating us to actively participate in competitions to providing invaluable assistance with our technical needs. Professor Soroush Farzin has truly gone above and beyond.

A huge thanks to Professor Leonard Albano and Professor Nima Rahbar. Their expertise in structural analysis and methodological techniques significantly contributed to our outcomes. Their presence and optimistic mindset elevated our MQP beyond just a report.

Thank you to Professor Brigitte Servatius and Professor Herman Servatius for the guidance...

A major thanks to Russ Lang for being the Lab Wizard. His patience and guidance were instrumental to our success! From guiding us through the operation of every machine in the lab to dragging and kicking our shredder across campus, we thank you!

Thanks to Paula Fitzpatrick for her kindness and optimism. We greatly appreciated the opportunity to expand our project into something that will positively impact our small community.

Thanks to Professor John Sullivan for setting the foundation and imitating 3D plastic research. And Mitra Varun Anand for providing and supporting 3D plastic.

Thanks to PhD candidate Mobin Vandadi. Mobin took charge of the structural analysis and helped convert our research and testing into real life applications

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Introduction

Throughout architectural engineering, one must navigate the complexity of design, functionality, and innovation to shape environments where aesthetic appeal seamlessly blends with structural integrity. Yet, the scope extends beyond mere form and function. Architecture demands significance; it requires a message aligned with an overarching objective. The essence of such creation creates a perfect harmony between beauty and strength.

As architectural engineering majors at Worcester Polytechnic Institute, we wanted to further embrace these two elements to work towards a larger goal on campus. We planned to use architecture and its natural beauty to create a comforting and tranquil environment for our campus. Consequently, our group wanted to be mindful of the sustainability of our structure. With these goals set, our project was developed around an international architectural competition, *Waste Pavilion*.

Throughout the competition, participants are encouraged to conceive visionary concepts for a pavilion constructed entirely from reused materials. The emphasis on material reuse should foster creativity and inspire innovative solutions to challenges such as space constraints and structural integrity.

The Pavilion not only sheds light on mental health in academia but also tackles waste management issues. Responding to the issue of discarded 3D-printed plastic at WPI, the Pavilion is constructed entirely from 3D recycled plastic. The goal was twofold: to raise awareness about interconnected mental health issues on campus and to shed a spotlight on the environmental impact of 3D printing waste. The Pavilion has six entrances, symbolizing common emotions on the mental health journey: anxiety, distraction, isolation, overwhelm, resentment, and security. Despite the differences, these emotional paths converge at a central point.

Background

Our pavilion design and consequent studies of PLA composites were motivated by WPI's mental health crisis, the rapid waste production the world is facing, and the ways in which architectural engineering can help combat such issues. The following sections provide an overview of the current states of sustainability and mental health, both globally and at Worcester Polytechnic Institute (WPI).

Sustainability

The world as a whole is producing more waste than ever before. The 2018 report conducted by the Environmental Protection Agency found that the total municipal solid waste generated in 2018 was 292.4 million tons, which is equivalent to 4.9 pounds per day per person. Of this generated waste, the largest contributors were paper and paperboard at 23.05%, food waste at 21.59%, and plastics at 12.20%. This report demonstrated a staggering increase in waste production even from their report conducted the year prior; from 2017 to 2018, the average American produced an additional 0.5 pounds of waste per day. Of this 292 million tons, 32.1% of it was either recycled or composted, with 68% of all recycled material being paper products. Since 1960, plastic has been the least recycled of all waste products, accounting for only 9% of all recycling in 2018.

WPI's recycling percentage actually falls below the national average. In 2019, WPI was recorded to only recycle 19% of its total waste. WPI's 8th Annual Waste Audit in a single day collected 477.2 pounds of waste from the Rubin Campus Center alone, 80.8% of which came from trash cans. Only 10.6% of the waste was initially recycled, and 8.6% was cardboard. Of the waste collected, only 55.9% of it was truly trash. The WPI Green Team, who assisted with the audit, reported that a portion of the trash could have been recycled had it not already been contaminated by other waste products. Additionally, 49.84% of all recyclable materials were placed in the wrong bin, demonstrating a consistent misplacement of recyclable materials on WPI's campus.

Creative strategies in the field of architectural engineering are being implemented to combat the growing waste issue that the world is facing. Common household waste products, including paper, glass, and metal, can now be repurposed to create structural building materials. Newspaper wood is created from the extreme pressing of stacked newspaper sheets. The end results are wood-like planks that closely match the tensile and structural capabilities of standard wood. Major support beams and building facades can be made of recycled metals such as steel, iron, copper, and aluminum. Other materials like glass, wood, and plastic have been repurposed and integrated into modern architectural designs.

Waste products have been used even more widely for aesthetic components in architectural design. Both the Zig-Zag House of the United States and the Plastic House of Dublin feature fully plastic facades made from recycled bottles and containers. To create these facades, the plastic bottles were melted down and remolded and recolored into sheets to be used along the houses' exterior walls. Pavilions have also become one of the most common ways for waste products to be recycled into architecture. Over the past few decades, pavilions have emerged as a prominent architectural form to convey urgency for recycling and waste reduction. The Head in the Clouds Pavilion, constructed in 2013 as the winner of the City of Dreams Pavilion contest in

New York City, made a statement on the plastic waste crisis of the city. The pavilion was constructed completely of plastic water bottles, specifically, the number of plastic bottles thrown away every hour in New York. The structure created a place that was not only beautiful, but forced the public to contemplate their own plastic consumption and truly understand the amount of waste the city produces. The Governor's Cup Pavilion, also located in New York City and the winner of the 2014 City of Dreams Pavilion contest, also chose to tackle the city's plastic consumption as their topic of interest. However, they chose to convey their message about the city's plastic consumption in a hands-on approach; residents of New York City were rallied and encouraged to actually construct the pavilion, allowing those who participated to understand just how much plastic was being thrown away. The act of building the pavilion brought the community together and allowed those who participated to feel connected to both the pavilion and the cause itself.

Mental Health

The mental health of college students has been rapidly declining since the COVID-19 pandemic. In the 2020-2021 school year alone, more than 60% of college students from 373 US campuses met the criteria of experiencing at least one mental health problem. A 2021 study was conducted comparing the mental state of first and second year college students before and during the pandemic. The study found a notable increase in clinical depression, alcoholism, bulimia, and binge-eating disorder among college students after one year into the pandemic, and most of these students are still in college today.

At WPI, undergraduate and graduate students' mental health needs have been increasing in severity over the past several years. In the fall of 2022, WPI conducted a campus wide survey and hosted multiple town-hall style meetings to better understand the state of student and faculty mental health. From the survey emerged major themes and concerns relating to mental health, notably overwork, work-life balance, a general lack of appreciation, and specific mental health challenges. The compiled data revealed that much of WPI's faculty do not feel appreciated, nor do they feel as though they have control over their day-to-day schedules. As a result from this study and findings from multiple national assessments (Healthy Minds Network, ACHA, NCHA), WPI pushed forward to create the Center for Well-Being, a location on campus dedicated to improving student mental health.

Creating spaces on campuses designed for student well-being has been shown to have positive impacts on students.

At (Worcester Polytechnic Institute) WPI counseling is offered through the (Student Development & Counseling Center) SDCC where individual counseling, group sessions and crisis interventions are offered. The school provides wellness days during which classes are suspended, allowing both students and faculty to relax and rejuvenate. On these wellness days, the (Center for Wellbeing) CWB organizes various programs dedicated to promoting relaxation and fostering connections...

Methodology

Architectural Pavilion Design

To capture the essence of an experience within our design we developed a form in which a student can enter through a variety of openings, travel along a pathway and reach a centralized internal space. Likewise, understanding the form from the inside-out, from this centralized space a student can chose an exiting path to travel along from a variety of options. The purpose of this form is to interpret how a specific path through life, or any situation, may not have one correct journey. Additionally, each path developed through our form creates a different environment for the student when it is traveled along. Although one chosen path may be the shortest distance towards your goal, it may strain you more than a longer path in which you understood more from would. The purpose of this in our design is to express how objectives in life will have varying approaches depending on how they are perceived but eventually the task will be completed.

Further developing the form, our group wanted to architecturally design the pavilion to truly raise awareness towards the mental health issue on college campuses. To do so, we developed to structure, so its center is not in view from its outside. To reveal the inside of the pavilion, one must take the journey through it to understand it entire completeness. This was done to express how many students are undergoing different types of stresses during this stage of their lives and an outside perspective may not be aware until they further engage. As seen above, this quality is portrayed through a series of curved walls following the circular path. The backside of one wall and the front side of the sequential wall creates paths for each student to journey through. The curved walls allow for there to be various direct pathways towards the center of the pavilion while sheltering its interior. Additionally, each wall curves overhead for a sense of shelter through most paths.

When differentiating the experiences each path endowed, we separated them by the types of emotion a student may feel when struggling with mental health: isolated, distracted, resentful, anxious, overwhelmed, and secure. To define the architecture behind each pathway, our group identified a list of parameters in which each emotion could be adjusted to match its intended feeling. These parameters consist of the wall height, thickness, length, transparency, degree of curvature, color, rigidity, and spacing between walls. We decided to adjust only the height, length, transparency, curvature, and inside spacing parameters to be able to create enough contrast between the walls to gain a different experience through the pavilion however, we wanted to keep an appealing, modern aesthetic to our design to encourage its use on campus. For example, we kept the outer wall spacing consistent between paths to ensure there is no bias when determining which path to travel through. Additionally, we chose to keep the thickness, rigidity, and color of the walls consistent for structural and aesthetic purposes.

Rhino and Grasshopper

Through our developmental process, our group used *Grasshopper*, an object-oriented coding extension used alongside *Rhino*. These softwares allowed us to input the various parameters necessary to build our form in a three-dimensional space. We were able to adjust our parameters as necessary throughout our design.

The arrangement of consecutive pathways was also a major influence in our design. Our group showed growth in our architecture by adjusting some of their parameters in a specific order. In our design, we started with a short, small, dark, tight, and narrow pathway to represent feeling isolated. This pathway is the only within the pavilion having both walls overhang its journey to represent a true enclosure. Traveling both counterclockwise and clockwise, around the circular pattern the walls follow, these parameters increase, staggering from side to side, until reaching the direct opposite side of the isolated pathway. Here lies the secure pathway with completely opposite parameter compared to the isolated path. This is a tall, long, bright, open, and spacious pathway. It is the only journey without an overhang as both of its walls, and consecutive walls after, curve track towards the isolated expression.

Material Selection

PLA

Polylactic Acid or commonly known as PLA is the most popular desktop 3D printing material available. PLA is a type of polyester constructed from fermented corn starch, maize and sugarcane. PLA has become the default filament because of its low cost, its ability to be printed at low temperatures and its extended shelf life. PLA is considered to be environmentally friendly as it's derived from renewable sources, however like most polyester very difficult to biodegrade. PLA under ambient temperature (25 °C) shows very slow degradation. Submerged in seawater for 6 months PLA showed very little degradation.

Source: https://www.sciencedirect.com/science/article/pii/S0141391014000226

https://www.sciencedirect.com/science/article/pii/S2214914719308530

	Polylactic Acid	**Jute Fiber**
Tensile Strength/MPa	47.8	200 - 440
Density/ (g cm^{-3})	1.11 -1.24	1.3
Youngs Modulus/GPa	4000	26 -32
Flexural Strength/MPa	80	N/A

Experimental Design

As college students at a technology institution, one of the most abundant sources of plastic waste, produced by academics, are 3D-printed PLA prototypes. Therefore, we wanted to make an impact on a method for sustainably up cycling this material. We have chosen to use this material alongside natural jute fibers to develop a composite material to use for the structural components of our pavilion.

Through our research we created three varieties of sample materials, each having a different PLA to jute ratio. These composite samples were then tested under three different tensile tests to test their performance in normal, hot, and wet environmental conditions. It was important for our group to test the tensile strength behind our composite material as polymers, more specifically PLA, are much weaker in tension compared to their compressive strength. Therefore, in our research, our group used jute fibers to increase the tensile strength of the plastic by creating a greater surface area of higher tensile strength for the polymer to bond on to. This is extremely similar to the role steel rebar plays when increasing the tensile strength in concrete, however, on a much smaller scale.

Composite Material Tensile Testing

Our group developed a series of tensile test specimens following the standardized shape and size below for polymers produced. We produced a total of twenty-seven samples, having a sample size of three per material variety for each of the three different tests we conducted for the composite material. For the samples, our group had to up cycle waste PLA prototypes and combine this with processed jute fiber.

Through our research, we have found methods for recycling PLA waste. These steps include collecting the waste, shredding it into small pellets, followed by washing and dehydrating the pieces. In most cases, this product was then reprocessed into filament to then be used for more 3D-printing. However, in our case of up cycling the PLA waste into a structural building material, we used similar steps following the recycling process and adapted following processing steps into a new methodology to create a composite building material, rather than filament. We created a method which could be sustainably used to create a building material in any shape needed, making it extremely versatile, similar to concrete. In the process, we took advantage of the low glass transition temperature of PLA compared to many other materials. By understanding this, we were able to melt down the processed PLA, combined with the natural jute fiber, and mold it into any shape necessary for architectural design.

Sample Preparation

The process of breaking down the PLA waste, previous student prototypes, started with collecting the waste from its source. We believed it was important to use waste material specifically produced by students on our campus because it emphasizes the impact that students, themselves, have towards making their world more sustainable. For our project, the entirety of the PLA waste we used to make these samples, as well as our final prototype, was 3D-printed by WPI students at our campuses largest center for 3D-printing, *Makerspace,* in the *Innovation Studio.*

After collecting over one kilogram of this waste we used a student-made shredder, seen below, developed from previous Worcester Polytechnic Institute Major Qualifying Project in 2020 advised by John Sullivan, *Reuse Plastic for 3D Printing*. The shredded consists of a standard wood planer, elevated on man-made cart. Attached to the planer are two claw-shaped wooden pieces, on rails, running perpendicular to the blade of the planer. These are contained in a box made of plywood and plexiglass with a hopper on top. To shred the plastic, we placed the waste PLA into the hopper of the shredder with the front claw piece pulled back to maximize interior space inside of the machine. The majority of the waste fit into the machine, as it was designed for this purpose, as long as the pieces could fit through the eight-inch square hopper opening. With the shredder full, the hopper lid was closed to ensure most of the material stays contained within the machine. Then, the machine was turned on and the front claw was pushed towards the blade while the back claw was kept stationary, acting as a wall. By pushing the claw towards the blade, this pushes all of the PLA pieces toward the rotating blades of the planer, where the pieces are shredded into cm pieces and fall into a standard five-gallon bucket placed underneath the shredder.

The issue now faced with these shredded pieces is their size. We found most pieces processed through the shredder were too large to repurpose when compared to the pellet size of previous research. Our process for further breaking down the PLA shred into smaller pellets consisted of two parts: continuous shredding through the student-made shredder followed by shredding in a food processor on a smaller scale. The first step towards this was to filter the sizes of the shredded material. We separated the pieces into three different groups of sizes. This was done through the use of three mess screens of varying sizes. With the largest pieces, our group ran these pieces through the student-made shredder once again. The medium sized pieces were ran through a food processor and these pieces were separated by size through the sieves again. Finally, the smallest pieces were an accurate size to be used for repurposing the material into a composite and matched the size of the pellets we found in our research. This process was repeated up to three times for the output pieces from the student-made shredder. From this process we collected approximately 1.2 kilograms of shredded PLA waste pieces.

The next step towards recycling the waste PLA is washing. This is to ensure only PLA is being used for our testing towards producing a composite building material by flushing out any dirt or other debris which may have attached to the PLA via the lab or equipment used. We transferred all of the pieces to a standard five-gallon bucket and rinsed them in cold water several times. We did not want any chemicals or heat to disrupt the chemical properties of the PLA. These pieces were then spread out in a thin layer among multiple aluminum foil pans to dry completely for several hours. After completely dried, we started the dehydration process for the plastic. This was done by placing these aluminum foil pans into a large oven at 40 degrees Celsius for six hours. This is because any moisture that has entered the PLA has the potential to break the interior polymer chains of the material and weaken it.

After dehydrating the PLA pellets, we have reached the stage in which most PLA is recycled before it is up cycled into, usually, 3D-printer filament. However, in our case we have adapted this method of up cycling into a method of our own for the development of a composite building. Rather than being heated and simultaneously forced through a hole to create a reel of filament, similar to a hot-glue gun, these reusable PLA pellets will be homogenously combined with jute fibers and molded into any variety of three dimensional shape. This starts with processing the jute fibers. This begins by bounding the strands of jute fibers together in the same direction and finely cutting them down to size from their several foot long strands with scissors. These are then combined with the PLA pellets to create a homogeneous mixture by running both through a food processor for two minutes.

Molding and Dogbone Development

Once both materials for the composite are ready, the mold for them must be created. The homogeneous PLA-jute mixture will be spread among this mold and heated to form its finalized shape. We made our mold using a two-part hardening silicone, *Mold Star 30,* which is heat resistant up to 232 degrees Celsius. This liquid hardening silicone was made using a 1:1 volume ratio of its two parts and mixed thoroughly. It is then poured over an inverse 3D-printed model of one's intended shape. In our case of testing the composite material in tension, we used the inverse mold shown below. As seen, this shape was particularly easy to mold as it only has a nonlinear geometry in its XY plane. Because of this, we were also able to 3D-print a container around the inversely printed shapes to hold the liquid silicone. After the silicone is poured into this shape, it is placed on a vibration table for 45 minutes, the silicone's set point, and then left in a controlled environment for an additional 5 hours and 15 minutes to completely harden. When the PLA-jute mixture is melted down, only the z-axis, of the casted shape, is affected linearly. This occurs due to the gaps between the composite mixture being filled in when melted, resulting in a shorter casted shape compared to its mold. This can be adjusted through making this axis of the inverse model larger before-hand or adding more PLA-jute material and melting once more to reach the desired height. Specifically for our tensile specimen, our group accounted for this by making the inverse mold taller in the z-axis.

In the case of creating an object with all dimensions being non-linear, a different method must be used. For this method, the inverted 3D-printed mold will have been printed with supports because of its abstract shape. Because the shape of supports is not wanted in the final casted design, the inverse mold cannot be attached to a container to hold the liquid silicone as it was in the above case. This is because not one axis can be flush with a linear surface. Therefore, a separate container must be used. To mold the silicone, we first started by placing this inversely molded 3D printed shape into a rectangular container. Then we poured the silicone mold around the shape. Because, the inverse shape will have air contained within it, making its density less than that of the liquid silicone, the inverse shape will float in the silicone. This is because most 3D-prints are not set to be entirely infilled. To submerge the piece, we placed a flat board on top of it while it was curing. This allowed only for its contact points of the inverse shape to be the only unmolded sections. The vibration table and control times to set are the same as above.

In both scenarios, the inverse shape was then removed vertically from the, now hardened, silicone mold. In the non-linear model, the top layer of silicone will have to be carefully cut on one edge and hinged back to remove the inverse 3D-print. Then the PLA-jute mixture is packed into the mold as tightly as possible to avoid as many air gaps as possible. The hinged back top layers are placed back in their original position and the final amounts of the PLA-jute mixture are inserted only through the contact points. This is then placed into a sealed oven, under a fume hood, with an exhaust fan, at 200 degrees Celsius for one hour. After cooling for an additional four hours, the model is ready to be taken out of the silicone mold. The points in which the composite mixture was placed will now look rustic and non-uniform. These portions of the model will need to be planed or sanded down depending on the method used for casting the shape. For our tensile testing specimen, we used a drill press with a moveable table in the XY-plane. This allowed us to plane down the model to the correct height and give it a smooth top edge. For the more complex model, only the contact points need to be sanded down and a belt sander can be used.

Results & Findings

Architectural Design

Our finalized pavilion design creates a space for students, struggling with their mental health, to relax and express the emotions they are inhabiting by traveling though the paths seen below and experience the journey we have designed through architecture. As seen below, the finalized architectural form spirals to create a hidden internal environment. This was not only done for privacy of the individuals experiencing the journey but also, to create a sense of wanting a deeper understanding of the unknown. Additionally, the balance between overall symmetry of the structure yet, individual differences in the pathways is represented. We developed a sense of growth, moving in both directions around the pavilion, revealing both ends of one's emotional level and a development of those in between. Our has visually created this illusion simply with form and orientation.

Competition Results

In the *Waste Pavilion* by *NonArchitecture Competition*, our team's pavilion design placed as a finalist in this international competition. For this submittal, the challenge was being able to express our architectural design as well as the meaning behind our pavilion only through the use of one graphic, which is shown below. We wanted to convey how the structure would be used in a real sense while also capturing the deeper details of its architectural beauty.

Center for Well-being Design

Beyond the architectural design of our pavilion, our group wanted to express our message in a way that would benefit the students on our campus. The inspiration and initiation for