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DEPARTMENT OF MECHANICAL ENGINEERING

3D PRINTER ENCLOSURE

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ABSTRACT

3D printing is a vastly growing industry with huge potential to disrupt traditional manufacturing processes. 3D printing uses much less material, allows for rapid prototyping and is much cheaper as opposed to established methods. However, 3D printing requires controlled environments in order to print high quality parts which could prove difficult in areas with limited control of the environment with high temperature, humidity, and ambient exposure to dust particles like in developing nations in Africa.

At Penn State University, the goal of the Humanitarian Engineering and Social Entrepreneurship program (HESE) is to design and build a portable and collapsible 3D printer to help 3D print medical equipment for doctors in developing nations in Africa where part shipments are costly and limited. In conjunction with the HESE program, this paper illustrates and designing and building of a collapsible enclosure for the Relief Bot printer to regulate temperature, humidity, and pressure to maintain an optimal 3D printer environment while in harsh conditions. Airflow experiments are performed to measure and test the ability of the enclosure to maintain a positive pressure environment as well as testing different filter materials to see which material is most able to keep out dust while maximizing the efficiency of the fan. The results of the experiments show that the positive pressure system is effective at keeping out dust while a filter made of pantyhose chosen for its availability and low cost effectively filtered out dust particles. The experiments validate the final design and merit the created enclosure for further temperature and humidity testing in conjunction with the Relief Bot printer.

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For their influence, support, and guidance.

I would also like to thank my family and close friends who have helped and supported me all my life to get me where I am today.

Chapter 1

Problem Description

The goal of this project is to design and build a collapsible case for a collapsible 3D printer. All of the components must fit into a 1600 Pelican Briefcase along with the 3D printer itself. The inner dimensions of the briefcase are 21.43”x16.5”x7.87”. The enclosure must be able to regulate temperature within an optimal threshold to uphold a high quality of 3D prints. The pressure of the ambient environment within the enclosure needs to be kept relatively higher than the environment to maintain positive pressure to keep out dust from entering through the natural air leaks. The humidity of the enclosure environment must be kept sufficiently low so as to not interfere with normal printer operation. The enclosure must be durable to withstand the extreme environmental conditions that may present themselves during usage like high heat, wind, rain, and fatigue. The case should also be as lightweight as possible to increase the ease of transport. Another criteria to maximize the ease of use, would be for the enclosure to be easy and quick to set up and take down for increased mobility and versatility. The materials used to build the case should also be cost efficient to increase the possibility of easy replacement of parts in case of accident or damage.

Chapter 2

Background and Literature Review

This chapter first begins with a background in 3D printing to justify the requirements stated in the problem description and why certain criteria were chosen as constraints for the final design of the collapsible enclosure. Knowledge of 3D printing is necessary in order to gain insight into the justifications and reasons why certain design decisions were made as well as knowing how to weight the advantages and disadvantages or each of the proposed designs. Next various literature is reviewed to characterize the need for a collapsible 3D printer enclosure as well as various methods of controlling temperature, pressure, and humidity and where there is a gap in the literature that will be filled by the research in this paper. Some different methods of collapsing structures is also investigated to look for an optimal design as well as to provide insight for the possibilities of new designs.

3D Printing Overview

3D printing, also known as additive manufacturing is a process where parts are built up one layer at a time to form three dimensional solid objects (Berman, 2012). Figure 1 shows a specific method of 3D printing called fused deposition modelling (FDM). Plastic is the common type of filament, but in recent years the range of materials has expanded to include nylon, metal, carbon fiber and other materials (W. Gao et al., 2015). As shown in figure 1, the filament is heated, extruded through a nozzle, and deposited in layers on the print bed one layer at a time until the object is formed. It is worth noting that there are many other types of ways that objects can be 3D printed but the scope of this paper focusses on FDM because the design of the enclosure is based off an FDM 3D printer.

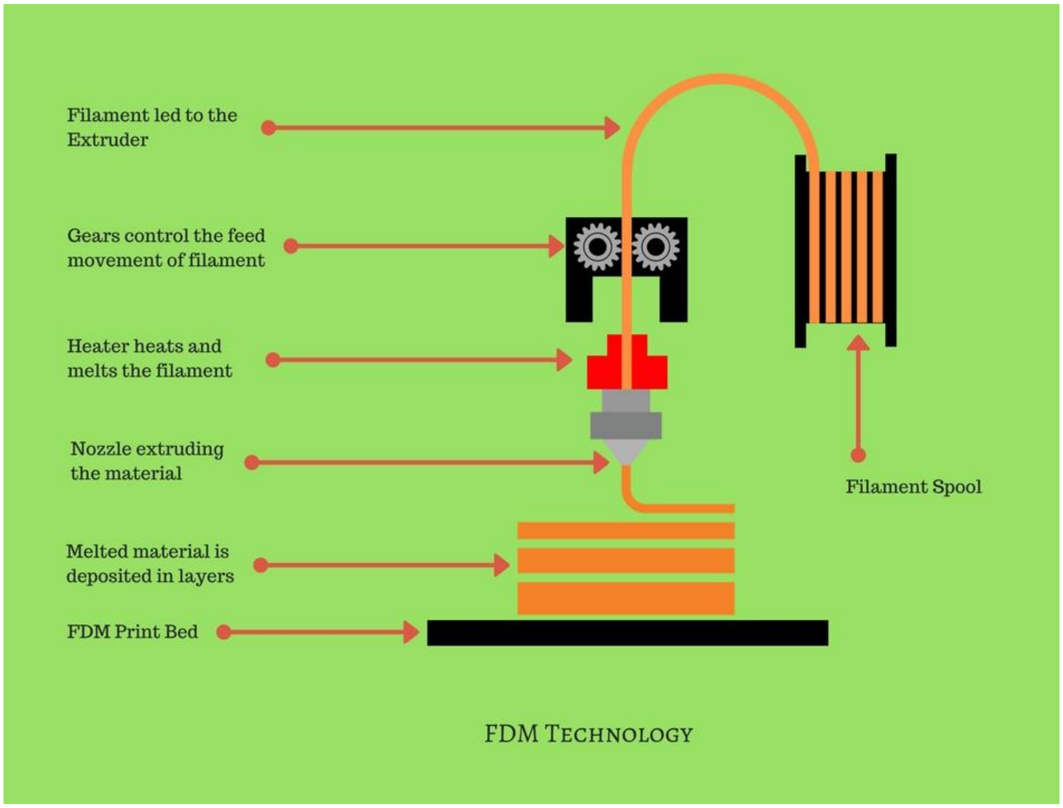

Figure 1: FDM diagram produced by Team Manufactur3D (Manufactur3D, 2018)

Benefits of 3D Printing

3D printing technology has such a potential to revolutionize manufacturing processes that some engineers, analysts, and investors are calling it the new industrial revolution (Kayfi, Ragab, & Tutunji, 2015). Additive manufacturing has gained much interest in the academic and industrial worlds, resulting in innovative research in the fields of machines, products, and processes which then affect the reimagination of manufacturing and structural logistics (W. Gao et al., 2015).

Additive manufacturing can also have a massive impact on inventory management and supply chain management because it can reduce or even eliminate lead time in receiving orders as well as shipping costs (Berman, 2012). 3D printing can also reduce the imbalance between export and import countries, lower manufacturing cost, and create new industries and new professions (Kietzmann, Pitt, & Berthon, 2015). Conceptual, verification and functional prototypes can be created rapidly at an extremely low cost, allowing the ability to rapidly iterate the design process that can be used for several purposes like learning, research, and marketing. Customized designs are easily produced which encourages the production of novel designs and can in turn, increase creativity.

Production of smaller batches sizes at lower costs can be achieved because no initial cost for special tooling is required as it is with traditional manufacturing costs. Also, the lead time on design consultations can be drastically reduced (Kietzmann et al., 2015). A designer in Germany can easily send a file or a part they created to be looked at by a potential marketer in China who can then print the part for themselves and provide feedback based on a visual inspection without having the technical knowledge of reading computer aided designs. The ability of additive manufacturing to produce small production batches with easy and reliable technology can cause an industrial revolution that allows small companies to compete globally in manufacturing products (Berman, 2012). Consumers can work with their 3D printers at home and produce their customized products (Mueller, 2012). These features are particularly useful for Penn State's Humanitarian Engineering and Social Entrepreneurship (HESE) program because its goal is to set up 3D printers in hospitals in Africa and 3D print medical equipment for doctors. Parts can be printed as needed without waiting for costly shipments from external humanitarian aid programs.

Potential Problems with Current 3D Printing Technology

While additive manufacturing has many advantages over traditional manufacturing methods, there are also some key disadvantages that have prevented 3D printing from proliferating to the mass market. There are some issues with timing for creating very large parts, but the most notable disadvantages are the resolution of the printer and the lack of high print quality for mass production.

One big concern with print quality is the mechanical properties of 3D printed parts compared to traditionally manufactured parts. In order to adopt 3D printed parts for use in real world applications, its strength in all aspects should be similar to the part that it will replace, or to those produced by conventional processing methods like injection molding since mechanical properties of additive manufactured parts can be affected by both the unprinted material properties and the manufacturing method (Berman, 2012; Dizon, Espera, Chen, & Advincula, 2018). In addition, polymers with defined functional and mechanical properties also have to be developed. In order for 3D printed materials to be ubiquitously accepted for usage, especially for building materials and for human safety, extensive testing still needs to be performed to fully characterize the mechanical and material properties of the 3D printed parts relative to the traditionally manufactured components before any 3D printed materials can be implemented. Usually, reinforcements/fillers are incorporated in polymers to enhance their mechanical properties, or by postprocessing (Dizon et al., 2018). Layered processing of polymeric materials, as is the case for 3D printing, has many issues that limit its applications. These issues need to be addressed for additively manufactured parts to have broad adoption in rapid prototyping and rapid manufacturing, as a means to employ 3D printing for the manufacture of high quality and reliable parts (Monzón, Ortega, Martínez, & Ortega, 2014).

Another issue with print quality is the effect of warping or curling which can occur to parts. Warping occurs because the temperature of the outside environment is much cooler than the temperature of the molten material, causing the material to rapidly cool. The rapid cooling of the part creates internal stresses because the material contracts when cooled which can deform the shape of the part and create inaccurate prints as shown in figure 2 (Wang, Xi, & Jin, 2007). This process can be catastrophic because if the shape of the part deforms drastically while the 3D printer is still printing, the positioning of the part can change and the new material being deposited gets deposited in the wrong place creating a potential print failure.

Figure 2: Effect of Warping on a 3D Printed Part

Steps have been taken to mitigate these effects by building enclosures around 3D printers to maintain a constant environmental temperature to increase print quality which is the aim of this paper. Many 3D printer models on the market like Formlabs, Dremel and Axiom offer 3D printers with enclosures already built into the design of the printers. Printing errors due to other factors are not part of the scope of this paper.

Big Problem and Motivation

The main problem that this paper aims to solve is that while 3D printers with enclosures already exist on the market today, these enclosures are rigid and difficult to transport on a regular basis. Penn State's Humanitarian Engineering and Social Entrepreneurship program (HESE) has designed a fully collapsible 3D printer with the goal of empowering social entrepreneurship in developing countries. The plan is to use the collapsible and transportable 3D printer to 3D print medical equipment for hospitals in developing African countries to replace the ineffective supply chain for delivering parts that exists today. The motivation of this research is to design an enclosure that will collapse down along with the collapsible 3D printer to control the ambient environment around the part while it's printing to ensure the highest quality part gets printed.

Need for a 3D Printer Enclosure

While the first part of the literature review highlights a main overview of 3D printing technology as well as its advantages and disadvantages, the remaining sections assess the literature on why an enclosure for a 3D printer is necessary to maximize the quality and function of the 3D printer along with an examination of the methods to control the temperature, pressure, and humidity. Literature on different methods of collapsibility are also discussed. As previously stated in the introduction, warping of parts due to temperature differences and internal thermal stresses remains to be an ever-present issue (Wang et al., 2007). The degree to which the thermoplastic material warps is governed by the cooling rate which is controlled by the ambient temperature of the environment (K.-S. Kim, Hahn, & Croman, 1989). The requirement to control the ambient temperature of the environment establishes the necessity for a method to control the ambient temperature for the 3D printer. As per the requirements of the problem statement to be discussed later, the 3D printer itself will be placed in a variety of temperature varying environments so an enclosure is necessary to ensure a reliable and constant print quality with minimized warping effects.

Another problem that would be mitigated through the use of a case for a 3D printer is the effect of dust. Several studies have shown how dust can interfere with common electrical circuit contacts and cause circuit degradation with dust accumulation (J. Gao, 2014; Kelly et al., 1995; Williamson, Greenwood, & Harris, 1956). Result were also confirmed by interviewing key stakeholders that operate the Relief Bot printer, determining that dust is a major problem that limits the effectiveness of the 3D printer. When the 3D printer was exposed to the ambient environment of developing countries while in use, dust would often collect rapidly over time and reduce the effectiveness of the 3D printer or cause the printer to short-circuit, reducing its lifespan. In this case, an enclosure would be effective because it would separate the printer from the outside environment so that the environment within the enclosure can be controlled to maximize the effectiveness and life span of the 3D printer.

In addition to temperature and dust, humidity also poses a potential problem because water absorption during a print can have significant negative impacts on the quality of the 3D printed part (E. Kim, Shin, & Ahn, 2016). Work by Eunseob, Shin, and Ahn showed that compared to an injection molded process, the tensile strength of fusion deposition modelled parts under dry room temperature conditions was 26-56% lower but the tensile strength of FDM parts under hot, wet environments was 67-71% lower, illustrating the magnitude that humidity can affect print quality. Other experiments by Halidi and Abdullah show that moisture effects on Acrylonitrile Butadiene Styrene (ABS) plastic cause physical, morphological and thermal stability changes to occur to the material. Upon prolonged exposure to moisture, the diameter of the ABS plastic increases, and the moisture effects the viscosity and flow properties change, leading to inconsistent performance of the 3D printer and likely failure (Halidi & Abdullah, 2012). Not only limited to plastic, research has been done by Morsali, Daryadel, Zhou, Behroozfar, Quan, and Jolandan on metal 3D printers and have found that relative humidity serves as a major factor in printing high quality parts because of its effect on the evaporation rate, affecting the meniscus which is critical for accurate metal 3D printing using a meniscus confined electrodeposition method. This process will not be discussed in great detail but it is worth noting that meniscus confined electrodeposition is done by using an anode electrolyte with a pipette to join with a cathode substrate, causing the metal to melt and deposit as electrons pass through which is similar to fusion deposition modelling but for stronger materials like metal (Morsali et al., 2017). In summary, previous research has shown the large impact that humidity has on 3D printing, and therefore it is essential to be able to control humidity especially in developing nations with high humidity and high heat conditions where the Relief Bot printer is intended for use.

An examination of existing literature shows that most other studies on 3D printing are done in sterile and already controlled environments like an entire room held at a constant temperature and humidity with little dust accumulation. However, the printer used for the HESE program will not be in such conditions and will often be subjected to humid, dusty, and temperature varying environments, so it is important to design an enclosure for the 3D printer itself to mitigate the negative impacts of these parameters.

Controlling the Temperature of the Environment

Since the need for an enclosure for the 3D printer has been established, the next section will highlight the existing research that has been done to control the temperature of the ambient environment as well as the gaps in the existing knowledge that justifies the need for further research. A study in 2014 showed that by increasing the temperature of a chamber surrounding the 3D printer, the warping deformation can be significantly reduced from about 2mm to .6 mm (Wu et al., 2014). By controlling the temperature of an enclosed environment, the cooling rate or the 3D printed part can be controlled and optimized for a higher quality part. One limitation to this study is that it is done for a polyether ether ketone (PEEK) material that is not used for the Relief Bot printer. While the general trend of reducing warping deformation by increasing the chamber temperature is noteworthy, there is a gap in the knowledge when it comes to more common 3D printer plastics like polylactic acid (PLA) or acrylonitrile butadiene styrene (ABS). Another study performed a finite element thermal analysis and compared them to infrared measurements and determined that maintaining an ambient temperature close to the glass transition temperature of the material allowed for much larger parts that could be successfully printed (Compton, Post, Duty, Love, & Kunc, 2017). This study specifically focusses on an area of 3D printing called big area additive manufacturing (BAAM) where dealing with much larger volumes on the order of m^3 often exacerbates effects of deformation and can drastically affect part quality. With larger volume parts however, larger deformational errors can be tolerated so the effect on smaller parts while keeping a high ambient temperature close to the glass transition temperature remains to be seen. Numerous other studies have been done to improve part quality and reduce warping through process parameters like nozzle temperature, scanning speed, extrusion speed, slicing orientation, thickness, or algorithmic techniques like bricking (Carneiro, Silva, & Gomes, 2015; Chari, Venkatesh, Krupashankar, & Dinesh, 2018; Guerrero-De-Mier, Espinosa, & Domínguez, 2015; Peng & Wang, 2010). But since these parameters are directly controllable through the 3D printer itself, they remain outside the scope this paper which is more concerned with controllable parameters through the perspective of a 3D printer enclosure.

Controlling Dust through Pressure

While various experiments have been done to study temperature in conjunction with 3D printing, no existing research has been done in relation with accumulating dust for additive manufacturing. Instead, studies have been taken from other research areas that can potentially impact how dust would collect for a 3D printer enclosure. The only reason dust is considered a problem in this paper is due to the unique conditions the Relief Bot printer and that it was considered a main concern from first-hand accounts of the team operating the printer itself. While no current literature is available that is directly correlated to additive manufacturing, other literature exists that can be examined so that further tests can be done in this paper. One study was able to successfully reduce the respirable dust particles by 87% in a mining operation by relying upon a positive pressure system meaning more air is being pushed into the system than is being pushed out (Noll & Cecala, 2015). With a filtration system on the intake, dust is filtered out and prevented from entering and the air blowing out pushes out any airborne dust particles already inside the system serving to drastically reduce the dust accumulation inside the system (Noll & Cecala, 2015). While this study was done at a mineral processing plant, the core ideas and principles remain the same. Field and laboratory studies have determined that the most significant components of an effective positive pressure system are: a competent filtration system comprised of a pressurized intake and a recirculation component and an enclosure with sufficient structural integrity to achieve positive pressurization. An effective pressurized intake air component provides numerous important functions in an optimized system. First, it provides the required amount of outside air to ensure acceptable indoor air quality as specified by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers. Secondly, it creates enough positive pressurization to stop dust related contaminants from being drawn into an enclosure. High-efficiency intake filters are necessary for an effective design (ASHRAE, 2010). This research mainly focusses on dust filtration for the purpose of improving air quality for humans inside the pressurized system, leaving a gap in the literature for the intended purpose of dust accumulation and its ability to short circuit electronic systems.

Another study investigates how a positive pressure ventilation system is used to filter the airflow in a school and clean dust out of the air to increase indoor air quality in the school (Vornanen-Winqvist et al., 2018). The results show that even small changes in air flow can have massive impacts on air flow rates and have noticeable effects on indoor air quality. While this study is still considered relevant to note, it is worth mentioning that the study mainly focusses on indoor air quality and cleaning out mold spores for public health rather than cleaning out dust. In the results of the study, dust was noticeably collected in the filters although it did not state how much leaving more room for research on dust accumulation in the application of 3D printing.

Other studies have been done using positive pressure systems to push out air but in the application of firefighting (Kerber & Walton, 2003; Lambert, Welch, & Merci, 2018). Kerber and Walton applied computational fluid dynamic (CFD) methods to show the velocity of the air at different locations within a room while a fan blows in air and compared it with an experimental setup to prove the concept in both theoretical and experimental terms. The research opens the door for further CFD research in several other configurations like number of fans, fan placement and their effect on the positive pressure system. Lambert, Welch and Merci's research focused more specifically on the ability for a positive pressure system to work if there was a fire in an underground subway. While still not directly applicable to dust filtration, the research highlights the importance on the number of fans and their placement in relation to the opening size for the air intake as well as the angle of the fan. The study showed that additions of more fans did increase output flow but the effectiveness per fan drops with each additional fan (Lambert et al., 2018).

While research has been done in a variety of other field in terms of pressure control, there remains an inevitable gap in the literature in directly relating dust accumulation through a positive pressure system for additive manufacturing purposes that merits further study.

Controlling Humidity

This section outlines the existing methods for controlling humidity with the goal of reducing humidity as it has been previously shown that higher humidity has negative impact on printing quality (Halidi & Abdullah, 2012; E. Kim et al., 2016; Morsali et al., 2017). Numerous studies have been done that use a variety of salt solutions have been shown to decrease the relative humidity of the environment (Solomon, 1951; Stokes & Robinson, 1949; Young, 1967). Solomon addresses many different acidic solutions that can be used at various densities to keep the humidity constant at different levels. While the research provides lots of options, the acidic solutions require careful preparation, require anti-heat resistant glassware and will burn skin upon contact (Solomon, 1951). Work done by Stokes show results for other solid compounds like NaCl, KCl, KBr and many other and their necessary concentrations to achieve relative humidities at 25 degrees Celsius. While the work gives more examples of safer compounds, the concentrations are only listed for 25 degrees Celsius leaving much room for improvement to explore concentration possibilities for temperatures much higher than 25 degrees Celsius. Young conducted a review paper and showed a relationship for different salt solutions of the change in humidity compared to the change in temperature over a given temperature range. While the ranges given were much larger there still remains a gap in the range of temperatures above 80 degrees Celsius. The nozzle temperature of a 3D printer can range up to 200 degrees Celsius with the chamber increasing to temperatures almost as high so further studies still need to be conducted to verify the validity of salt solutions reducing humidity at high temperatures. Other disadvantages of these systems are that different salts are needed for each humidity, a salt for a specific humidity may not be available, many of the salts are corrosive, and the equilibrium relative humidity (RH) formed over many solutions varies widely with temperature (Forney &

Brandl, 1992). Non-saturated solutions also can be used to produce various equilibrium RHs, depending on the concentration of the solute. The benefit of Forney and Brandl's work is that a single substance of glycerol water solutions in varying ratios of glycerol to water can be used to control the environment at any humidity desired. The study mentions some adjusted values for varying the temperature for 0, 25, 50, and 70 degrees Celsius with little change in the relative humidity but does not confirm the effect of changing the specific gravity of the solution on relative humidity at much higher temperatures.

While many methods to regulate and control humidity have been studied, no current research exists to control humidity at an enclosure level under high humidity and high heat environments, highlighting the importance of further testing to optimize the humidity controlling aspects of a 3D printer chamber.

Collapsibility

There are many ways a structure can collapse down to take up less volume. While there are many mainstream ideas that have become ubiquitous in commercial uses like hinges or connectable small parts like Legos, this section will explore novel academically researched options that can potentially aid in the construction in a collapsible case.

Several patents have shown ways structures can be designed using connectable pieces, or conversely, patents showing a case for a 3D printer that collapses down into a smaller volume (5469003, 1995; 6494335B1, 2002; D733196S, 2015). These patents show that people have worked on ideas for collapsible folding and 3D printer enclosures as separate ideas and future work needs to be conducted to combine these into one design.

Extensive work on origami paper folding has be done that can also apply to ideas for designing collapsible structures (Dudte, Vouga, Tachi, & Mahadevan, 2016; Reis, López Jiménez, & Marthelot, 2015). Reis, Lopez, Jimenez, and Marthelot extensively show how innovative origami designs have been used in structurally sound buildings to fit together for easy deployment and use using tubular building blocks to create a single rigid and stable structure. Other work shows how any curved structure can be created from a flat sheet using origami tessellations, highlighting how future designs can created using these tessellations and then collapsed down for storage (Dudte et al., 2016). While the previous resources show various implementations and methods for creating the origami folds for already completed structures, they do not provide methods for computing new origami shapes for the purpose of creating any desired shape.

Another approach uses over curved circles to collapse down as desired structure. This property is often seen in tents or foldable laundry baskets as shown in figure 4. The process works by using saddle shaped rings and overcurving them in a process shown in figure 5 to shrink the total circumference of the circles to a significantly smaller space (Mouthuy, Coulombier, Pardoen, Raskin, & Jonas, 2012). While minor adjustments have to be made to make this idea work for a functioning 3D printer, the idea can be directly applied and studied in 3D printing applications in future research.

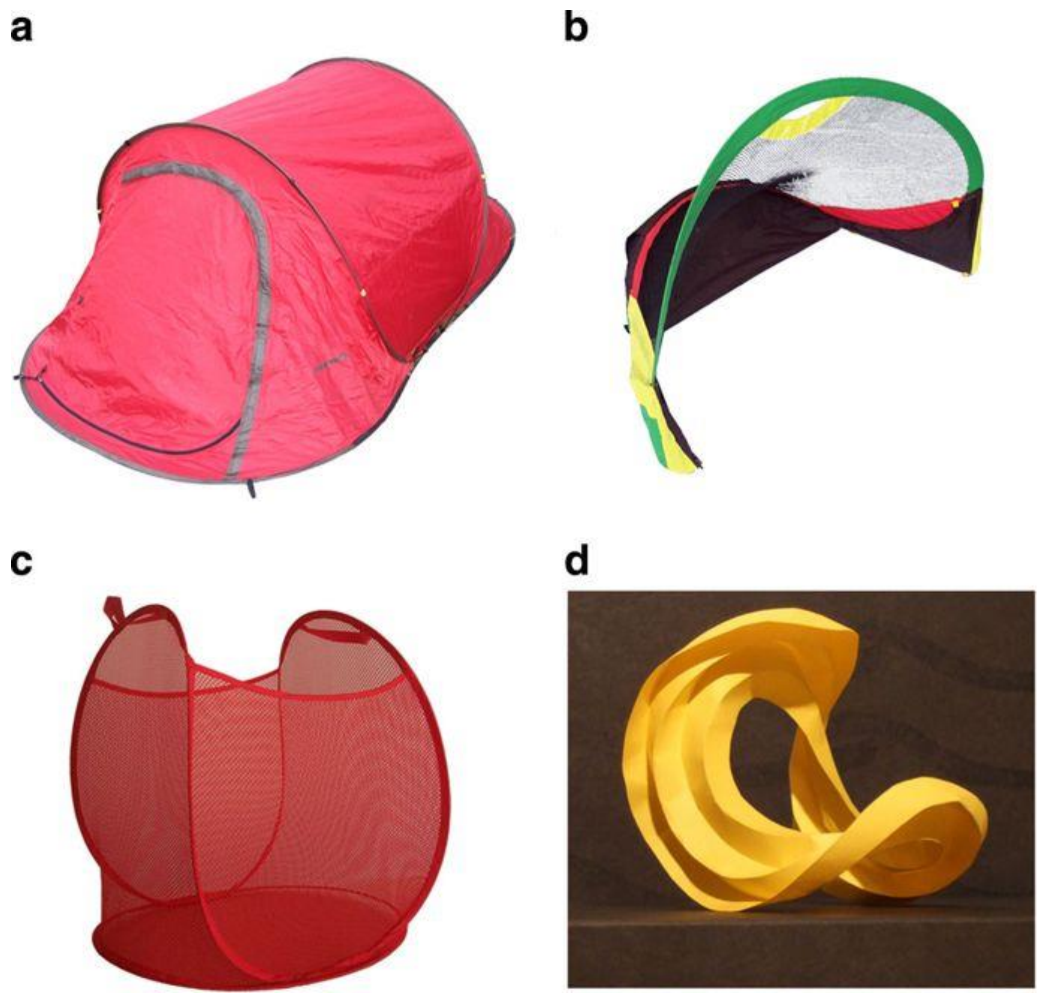

Figure 3: Show common objects that use overcurvature. a) a tent b) a foldable soccer goal c) a foldable laundry basket d) an origami circular crease

used with permission under creative commons license (Mouthuy et al., 2012)

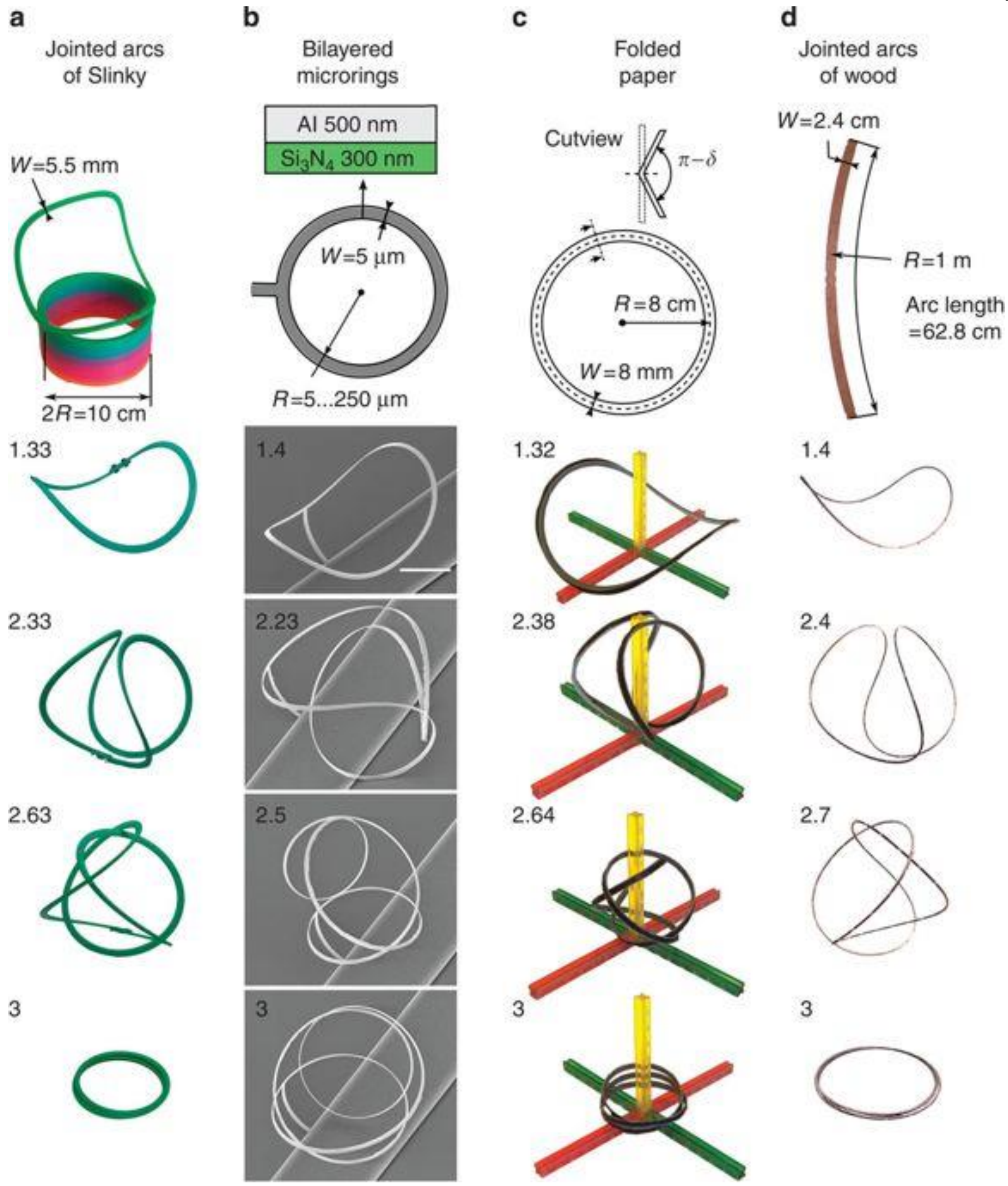

Figure 4: How various rings fold into a smaller space

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Summary of Literature Review

Experiments have shown that by controlling the temperature of the 3D print environment, warping effects can be diminished although this has only been shown for polyether ether ketone materials and not more common 3D printer materials like PLA and ABS plastic. Warping has also been shown to decrease when temperatures are maintained close to the glass transition temperature for large manufactured parts but the tolerances are much wider than for smaller parts. Positive pressure experiments currently show success for keeping out dust in large scale manufacturing operations or schools but there is a gap in the literature when it comes to testing smaller enclosures. There are various salt solutions that can be used to minimize the relative humidity as well as glycerol water mixtures that can be used to maintain different humidity levels at a variety of temperatures. There are also a number of methods like origami paper folding, disconnecting pieces, or the property of overcurvature that can be used to collapse down the volume of a design.

With a better understanding of the methods to control temperature, pressure, and humidity as well as different methods of collapsing into a smaller volume and the gaps in the literature, preliminary designs can now start to be proposed.

Chapter 3

Design and Implementation

Based on the literature review, this chapter summarizes the design process of creating the collapsible case. This chapter highlights the various designs that were created as well as the reasoning behind why certain design decisions were made. The early stages of the design process include some preliminary designs drawn on paper and discusses their feasibility and ultimately why certain designs were furthered while others were abandoned. Next, initial prototypes were built of the most promising designs followed by further prototypes increasing in functionality and detail. The prototype phase acts as a proving ground for the most successful designs to flourish while less successful designs get phased out. Prototyping also has importance in making minor adjustments to successful designs to make them easier to build or just better in general because in building the prototype, building and implementation problems become apparently clear which can be fixed or modified for the final implementation.

Preliminary Designs

Before building any prototypes, preliminary ideas need to be sketched out on paper to determine their validity. This process is important to rule out ideas that may sound feasible but end up not making sense when drawn out on paper.

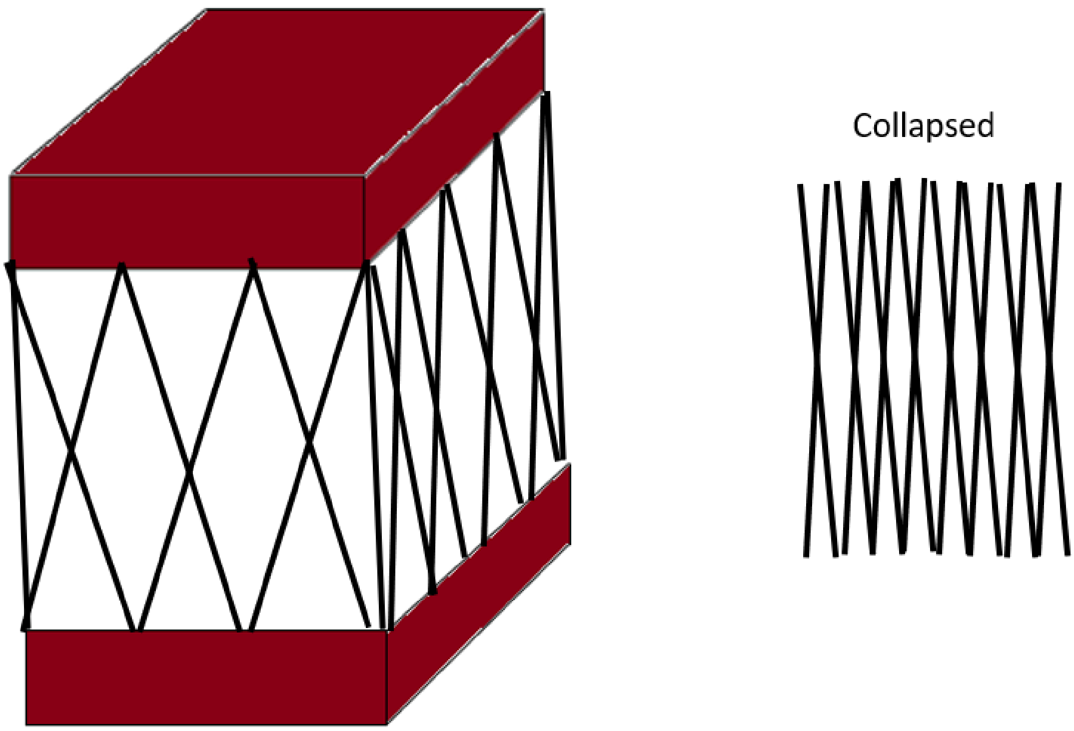


Figure 5: Collapsible Truss Structure

The figure above shows a truss like structure that would support the overall cover for the 3D printer. Similar to a fold out lawn chair, the truss structure would then be able to collapse down to a thin column as shown in the figure for easy storage. Some pros of this design are that the truss structure would be very strong and sturdy, able to withstand a lot of weight if objects like sensors or fans needed to be hung on the sides of the structure. Some disadvantages of this design are that even when collapsed, the structure can be bulky to carry around and would likely need a separate case of its own to be stored. Also because of the extensive framework of trusses covering the sides of the case, there would be low visibility of the user being able to watch the 3D print take place.

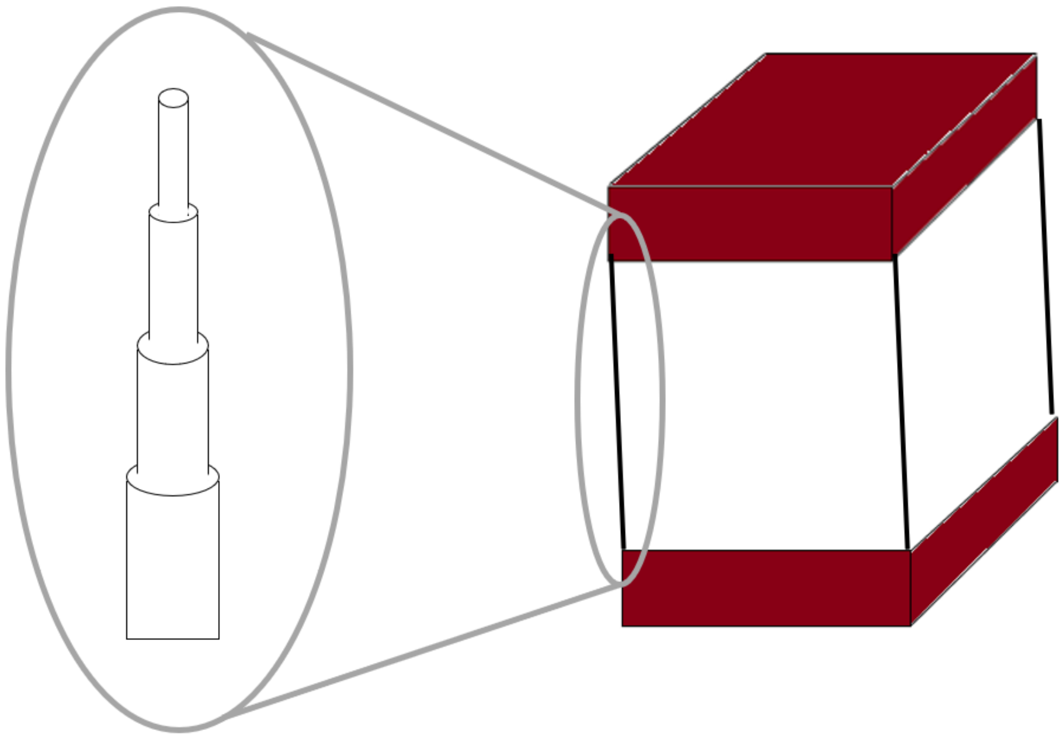


Figure 6: Telescoping Pole design

The figure above shows a series of four poles with a telescoping feature that allows each individual pole to collapse down in on itself like a nesting doll. The pole is broken up into multiple segments where as one goes progressively upwards, the diameter gets progressively smaller as shown in the figure, allowing each segment to fit inside the other. This telescoping feature has the advantage of shrinking down to a small volume for easy storage. The design also uses a lot less material relative to the previous design, meaning that the overall design will be a lot lighter which allows for much easier transport when travelling with the overall case. A possible disadvantage of this design is that it is unclear if the poles can support the necessary weight. Another problem is that there is no easy mechanism to keep the segments of the telescoping pole from staying extending. To implement the design would require a mechanism like some sort of insert to hold each segment which could become time consuming to set up and take down if the 3D printer is being transported enough.

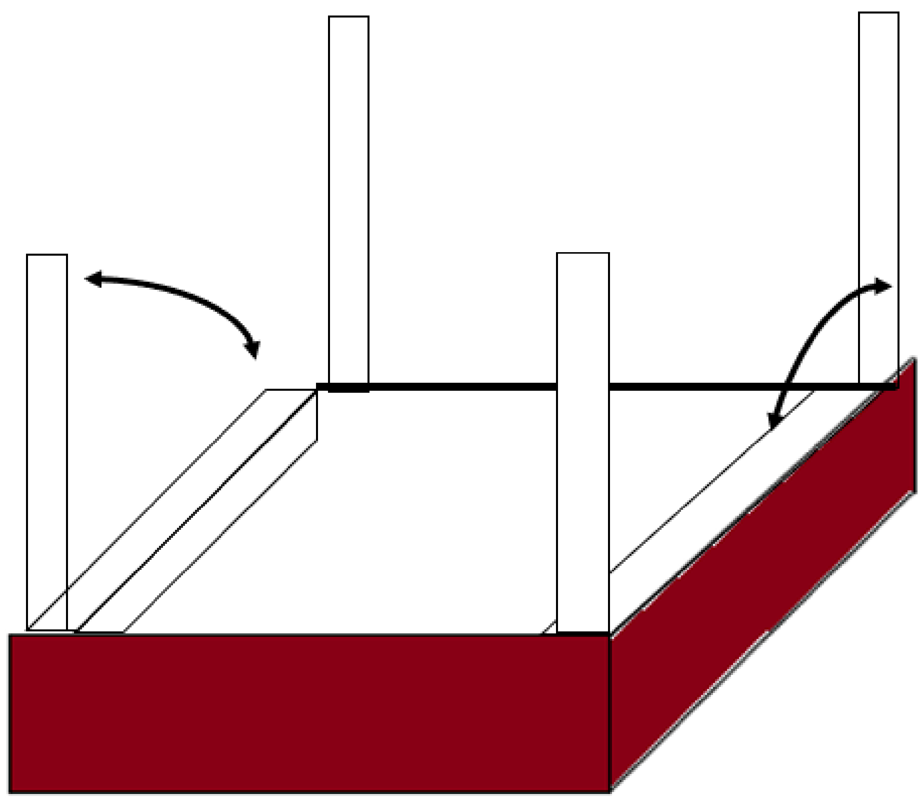


Figure 7: Hinged Poles

The figure above shows four rigid poles attached at the bottom to the floor of the case by a hinge. Depending on the materials chosen, a rigid pole can be strong to hold up any required add on equipment as well as being incredibly simple in nature and easy to replace in case of breakage. The hinges at the bottom allow the design to be easily and quickly set up and taken down. Some added complexity may be necessary because if both sets of two poles collapse down along the length of the briefcase, the poles would knock into each other, so an adjustment would have to be made if this design is pursued further. Another possible drawback would be that the poles may take up valuable space in the briefcase along with the 3D printer. Further work in determining the other components that make up the case needs to be done to in order to determine all of the parts together will fit inside the case.

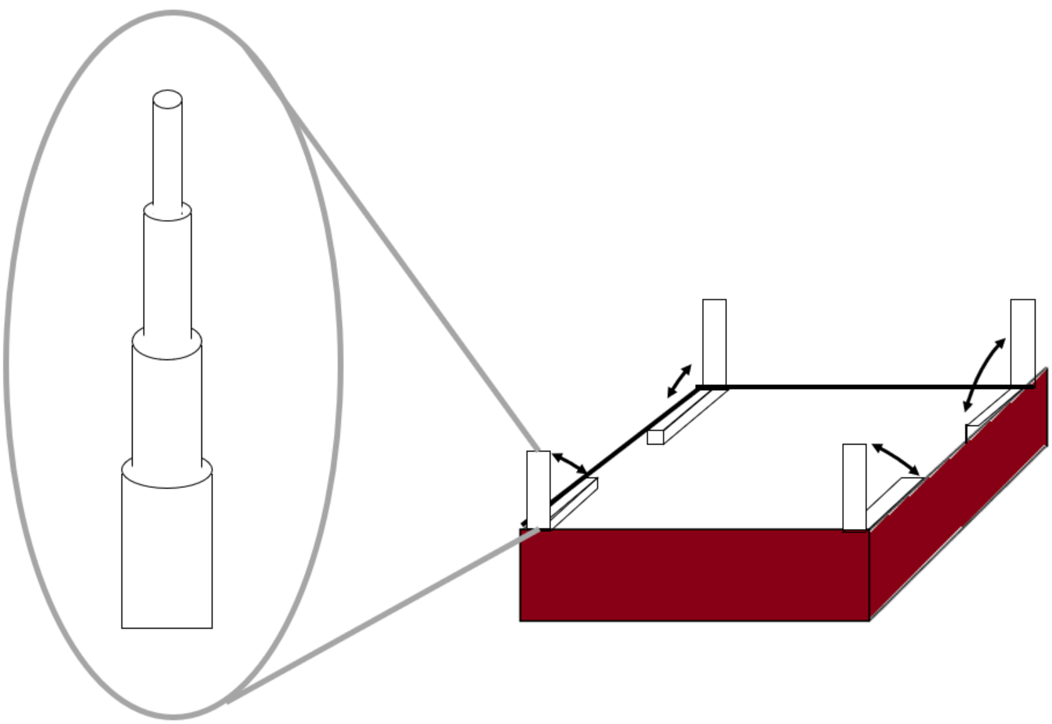


Figure 8: Combination of Hinged and Telescoping Poles

The figure above is a combination of the previous two designs. The telescoping poles with hinges connecting to the bottom of the briefcase has the combined effect of taking up even less space inside the briefcase. It solves the previous problem where now the poles will not interfere with each other when swung down and collapsed. Some disadvantages of the design are that now with the segmentation of the poles, the poles may not be as strong as the regular hinge design. The design also contains the drawback of the telescoping pole design where an added mechanism needs to be put into place to support the expanded segments. The added supports increasing the set up and take down time of the case could prove to be costly and burdensome if the case is transported often.

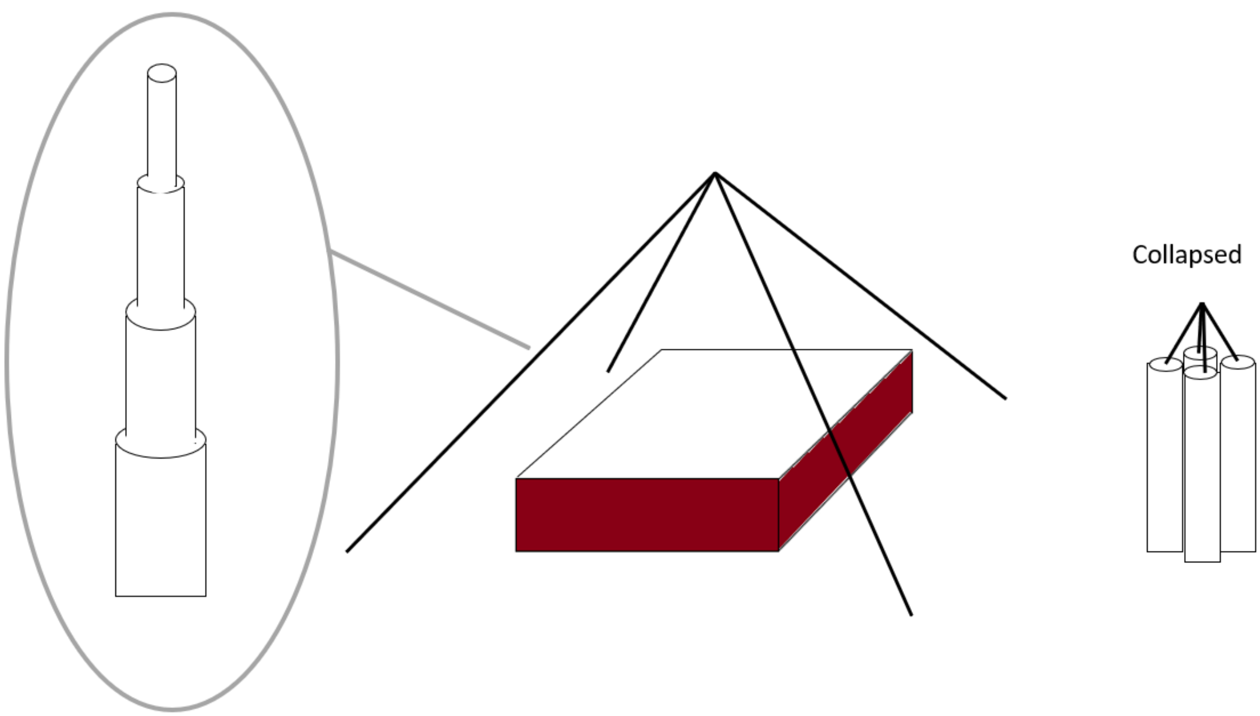


Figure 9: Pyramid Tent Design

The figure above shows an extendable pyramidal tent like support structure with the ability to collapse as shown like common tent poles. The advantage to this design lies in its simplicity of concept and easy ability to set up. The pyramidal structure has used for thousands of years because of its simplicity and fundamental strength in shape for building large structures like the Pyramids of Giza. Some potential disadvantages of the design are that it takes up a much larger base area due to its pyramidal shape which could be problematic during the operation of the 3D printer as well as the collapsed structure could prove to be bulky and may require an additional case to store. It could also prove difficult if any attachments need to be made to the structure due to the awkward angle of the pyramid.

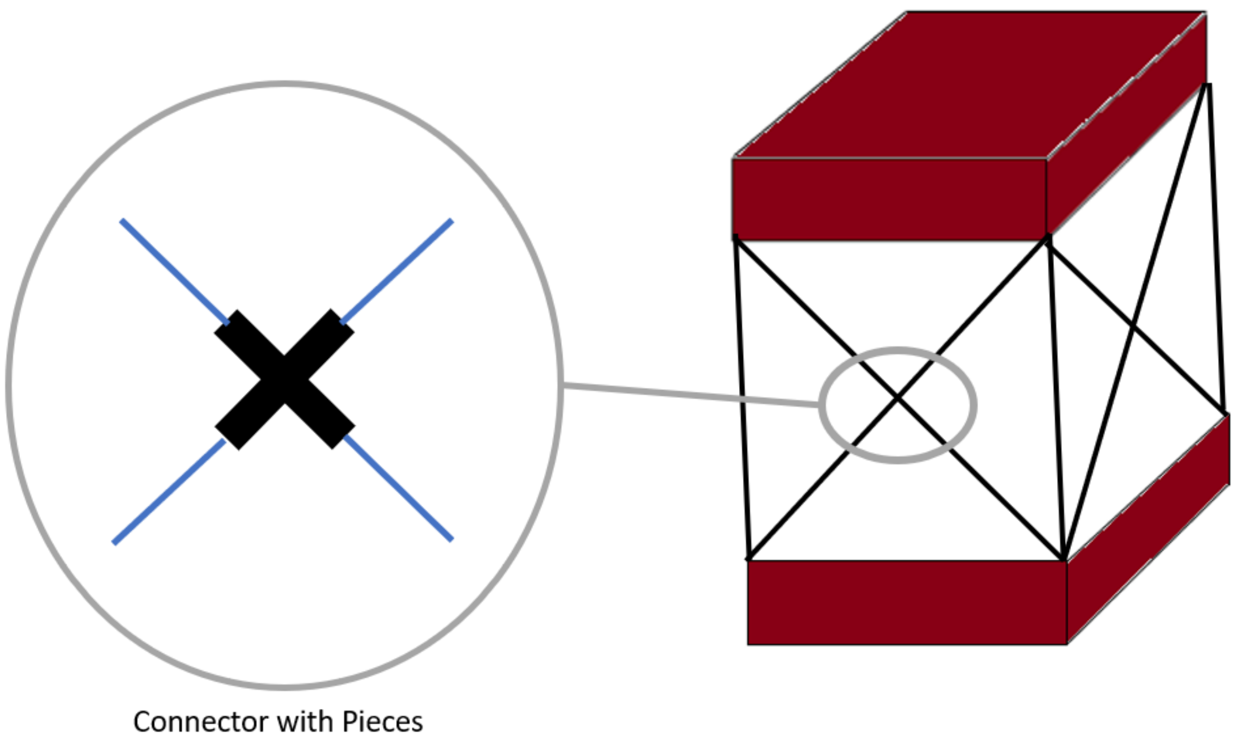


Figure 10: Truss Design with Connectors

The figure above is similar to the first design because of the truss like structure but differs in its ability to collapse down. Instead of being one full piece that folds up, this design would be comprised of many pieces that connect together to form the truss design. The advantage to this design is that there is a high degree of repeatability so that parts can be easily replaced with one another in case of breaks or damage. The truss structure is also very strong in its ability to withstand external stresses and can also easily support any added equipment that may need to be attached on the top or sides of the structure. Replacement parts also can also be 3D printed as necessary adding to the ease of replaceability. A possible disadvantage is that a myriad of pieces could prove to be time consuming to set up and take down. There could also be issues with viewing the 3D part while it is printing.

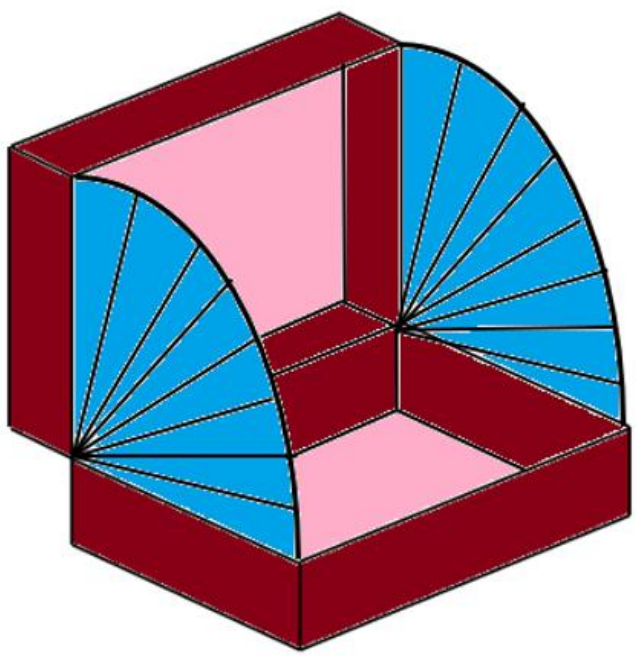


Figure 11: Fanned Edges

The figure above shows the full briefcase open with large fans attached on each side of the briefcase. At the ends of the fan, there would some sort of rigid component so a cover can be placed over top. A major advantage to this design is that it incorporates the back of the briefcase as part of the design, limiting the need for more parts which reduces the complexity and overall weight. The folding fan concept is also an advantage because it is very light weight and collapses down relatively much more than the other designs. The main disadvantage is that the curved ends of the fan do not cover the entire build volume which is a necessity so modifications need to be made. Also, depending on the material the fan is made of which is typically paper, there is a chance that the side of the fan can be easily punctured. As of now there is now way for the rigid parts of the end of the fan to collapse down so that could be problematic as well.

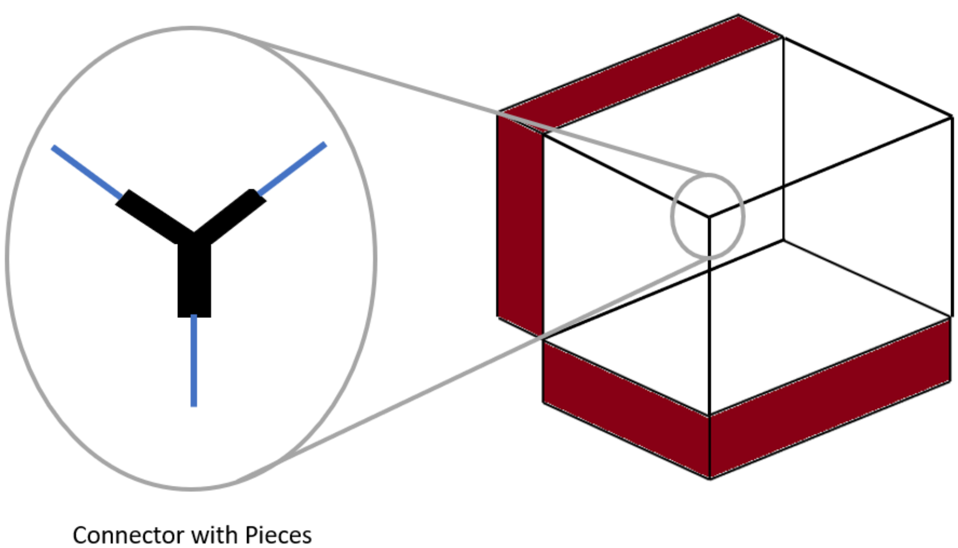


Figure 12: Simple Square Box with Two Connectors

The figure above shows five straight column pieces attached to the end of the box by an insert and connected to each other by two connectors. The advantage to this design lies in its simplicity. There are a total of seven pieces where four out of the five poles are identical which is beneficial for repeatability and ease of replacement. The replacement parts can easily be 3D printed if necessary. The rigid poles are likely strong enough to support the case as well as any additional equipment that may need to be attached on the sides. The design also incorporates the back of the briefcase as part of the design to reduce the complexity and number of parts necessary. One possible disadvantage could be that the design may not be as strong other designs.

While each of the designs presented had advantages and disadvantages, the designs that seemed to hold the most promise were the fan and the box design due to their simplicity over other designs, high degree of collapsibility and ease of set up and take down. In the next section, further investigation of these designs will be done by building initial prototypes to test out these concepts.

Prototypes

After considering many of the initial concept ideas, a few of the most successful concepts were chosen to be further pursued in the form of building initial prototypes. This stage of the design process allows for a quick estimate of feasibility and can highlight some areas of design that may need further investigation.

One design that merited further investigation was the fan design. While the early concept depended on a fan, the design of the prototype was adapted to be more aligned with the idea of a window blind or the bellows of an accordion. An initial design was created out of cardboard and paper as shown in figure 14.

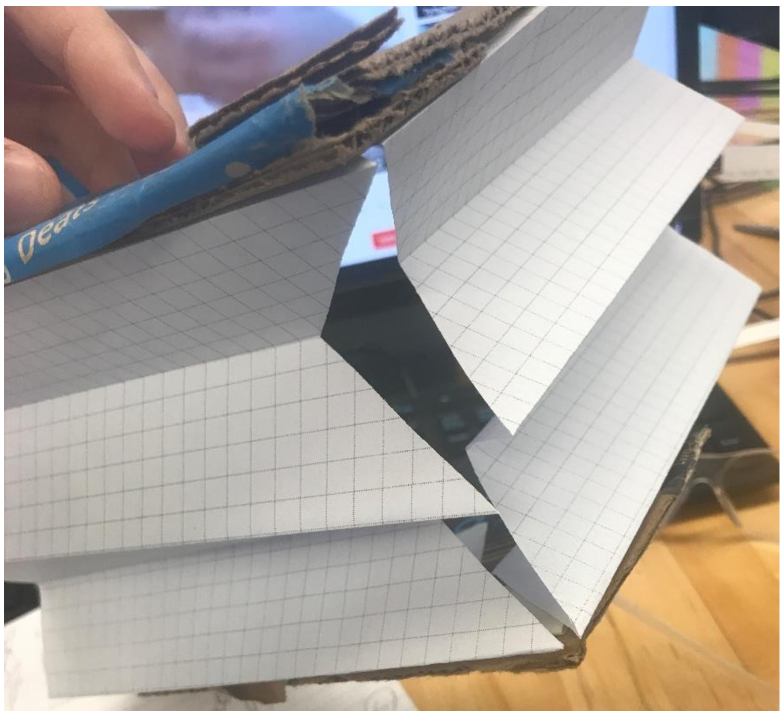


Figure 13: Carboard and Paper Accordion Bellow Design

The initial prototype shows promise because the paper is extremely collapsible into a very small volume. One thing that did become clear was that there needs to be a way to seal up the diamond shaped holes on the ends of each side as shown in figure 14. Another issue that became clear is that in order for the accordion design to stand up, there needs to be a rigid structure in place on the inside to support the exterior collapsible accordion design. While results for this design, are still promising further design and prototyping need to be done to know for sure.

In order to accompany the accordion design, a rigid structure prototype is shown in the figure below. The design in its final stage would be much thinner using a steel or aluminum material but for simplicity and cost effectiveness, the design shown is modeled with cardboard, wood, and duct tape.

Figure 14: Support Structure for Accordion Design

The support structure consists of four vertical square poles each with a castle like top of four squares, one in each corner. Then four U-shaped bars would be placed on top and inserted into the space the four castle-like corners of the vertical bars as shown in the figure above. Through observation, the rigid structure is easy to set up and take down, but at the additional cost of eight extra pieces four of which will be difficult to recreate on a smaller scale and also difficult to replace if damaged.

Next, the accordion design was recreated out of cardboard to match the previously created rigid structure as shown in the figure below.

Figure 15: Cardboard Accordion Design

Upon further observation as shown in the figure above the accordion design would be ruled out. Despite its initial appeal, when built as a full-scale prototype, the design does not collapse down as much as previously due to the much thicker material of the cardboard. Some material would also need to be used on the edges to seal up the holes which would restrict the ability of the accordion bellow structure from expanding as much as it could without the material sealing the corners. There is also the issue that the accordion bellows would add a lot of extra volume to the necessary briefcase, making the entire set more difficult to transport in between prints in separate locations. Another issue is that this design also does not address how the case will be covered on the top. The extra volume, the less than expected collapsibility of the structure, the lack of answers for connecting to the top and the added complexity of adding the rigid structure all together were ultimately why the accordion design was ruled out in favor of a simpler design to be discussed next.

The next design proposed originally had zippers along all the edges that would meet in the corner to seal up the case. In order to take care of the hole between the zippers, a Velcro patch was experimented and built as shown in the figure below.

Figure 16: Velcro Patch

The patch as a final design would be entirely Velcro but as shown the Velcro was cut into pieces to conserve material. The design was also tested under fans trying to blow in sawdust and no sawdust was visible in penetrating the Velcro seal. Eventually this design was deemed unnecessary due to the positive pressure system that would be blowing air out of the hole between the zippers. The hole is small enough and the air is strong enough to keep out any dust or debris. Although the design was eventually rejected, it is important to show the progression of the design process and in case future research may require something similar for a different purpose or use.

The next iteration of the design phase was marked by the creation of a model case made of wood as shown in the figure below.

Figure 17: Prototype Briefcase

There are only two poles on the briefcase because the cover design goes fully around the entire case, allowing for the back of the briefcase to function as a part of the walled support. Using the back of the briefcase instead of additional supports minimizes the need for materials and adds to the simplicity of the design. The cover, shown below was constructed using a six-gauge clear vinyl sheet, sewed together to a large zipper and covers the edges of the vinyl. The clear vinyl allows for easy visibility to view a part while it is printing and the zipper allows for quick access and set up.

Figure 18: Clear Zipper and Vinyl Cover Prototype

The next figure shows the prototype briefcase with the cover in place. The zipper covers seven of the twelve edges of the cube and only one large zipper increases the simplicity and ease of use.

Figure 19: Prototype Briefcase with Cover

Final Design

The figure shown below illustrates the finial briefcase cover. The dimensions of the cover were updated to match the outer dimensions of the 1600 pelican briefcase bought for the project. The cover consists of two side pieces with dimensions of 23”x26” and one big long piece with dimensions of 25”x98” sewn together with a zipper sewn around the outside. There are six zipper pieces to create three openings for inlet fans, an outlet fan, and an opening for easy access to put in and remove 3D printed parts. At the ends of the zipper, the edges are extended diagonally inward so that the zipper pieces can rest there when folding up the case, allowing the case to fold up neatly for storage.

Figure 20: Final Design Cover

Inside the briefcase itself there is enough room for the storage of the case along with fans, the support poles, and temperature, pressure, and humidity sensors that will be used to control the fans to regulate these conditions.

A major challenge in creating the prototype that was later solved in the final design was that placing the plastic material directly on the sewing machine caused the machine to not grip the material properly, messing up the bobbin thread. The result from the prototype caused an extremely messy sewing job with thread getting tangled up, leading to an undesirable and unreliable bond between the vinyl material and the zipper. To solve this problem for the final design, a protective cover of fabric was placed over the vinyl so that the sewing machine could correctly grip the material which yielded a much better sewing job.

Figure 21: Final Design Cover Folded Up

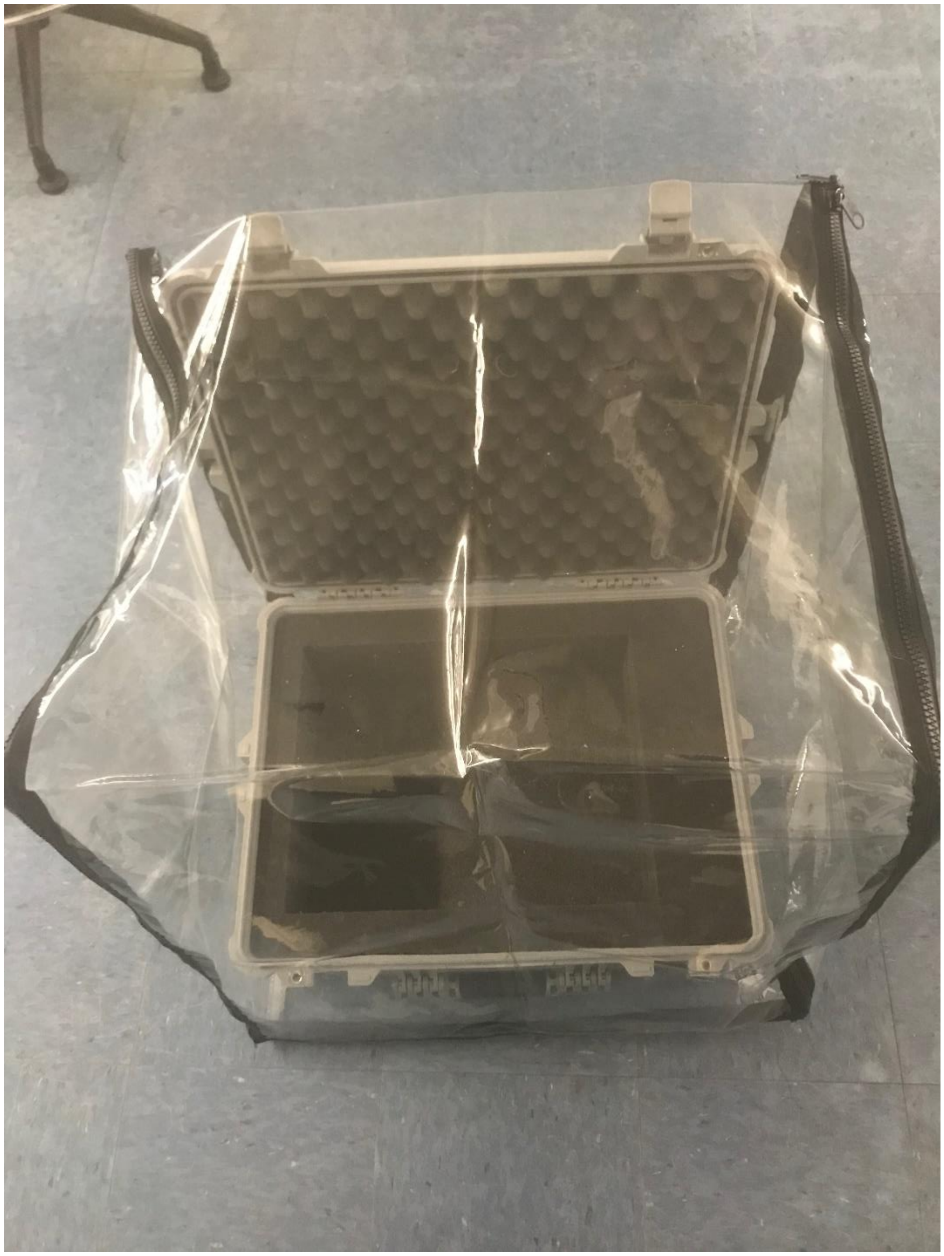


Figure 22: Final Design Cover in Use

Chapter 4

Results

In order to test the validity of the design, tests must be conducted to ensure that the design meets the design requirements described in the problem statement. In this section, airflow experiments were conducted to test the validity of the positive pressure system in the application of an enclosure for a 3D printer as well as the testing of whether dust can pass through a number of filters. Positive results for these experiments will validate the design and deem it ready for use in the field.

Filter Experiments

In this experiment, a few filters were created out of cheap and easily accessible materials and then tested to see if dust passes through the filter when a fan is blowing air through the filter. The cheap household items used were cut up socks and pantyhose due to their tight knit design to filter dust as well as their breathability to allow air to pass through them. A twelve-volt DC fan was used which was then covered in the filter material so that the dust would be filtered out before entering the fan. Sawdust and dust off the floor were gathered and used to model the passage of dust through the filter. Both filters were shown to be successful but at the consequence of a reduction in air speed blowing out of the fan. The reduction in air speed would minimize the positive pressure effect and make it more likely for dust to enter the case through other air leaks. The sock reduced the air speed exiting the fan considerably while the reduction in air speed from the pantyhose was minimal. Based on these results the chosen filter of the final case was pantyhose due to its low cost, ability to filter dust, easy accessibility, and minimal reduction in air speed of the fan.

Positive Pressure Experiments

In this experiment, the validity of the positive pressure system was tested and verified. A verification of the positive pressure system indicates that the designed enclosure will be able to keep out dust from the enclosure by having air being constantly pushed out from any air leaks in the case, and thus preventing dust from entering. In order to test a positive pressure system, three twelve-volt DC fans were used where two fans functioned as the input fans while the third fan functioned as the output fan. To obtain the most accurate data a test enclosure was created out of cardboard as shown in the figure below.

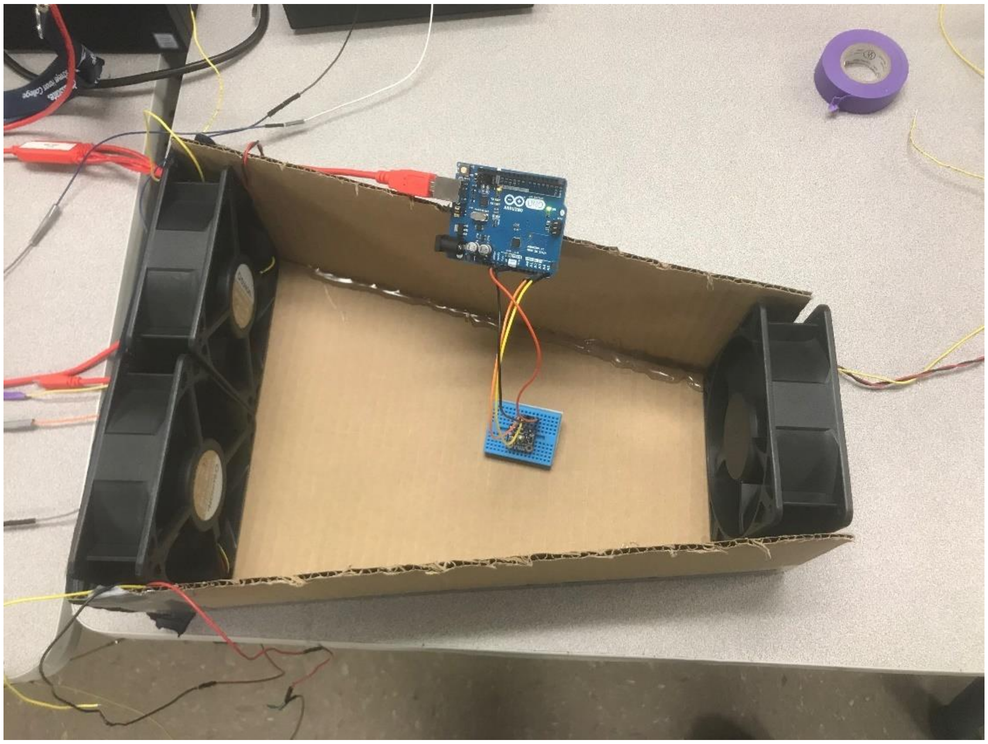


Figure 23: Positive Pressure Experimental Setup

The setup shown contains an Arduino controlling a an Adafruit MPRLS pressure sensor that measures the pressure inside the chamber between the input and output fans. The setup is shown upside down to see inside the chamber but during the experiment, the setup flipped so that the chamber is closed off and no air can enter or escape besides through the input and output fans. While in actuality some air will escape out of the sides, the model will be similar in the final design because of inherent air leaks in the system. The code and setup for the Arduino code and wiring of the pressure sensor are shown in the appendix. The pressure was measured continuously before the fans were turned on, when the fans were turned on, and for a little bit of time after the fans were turned off. The results of the first experiment with just the fans with no filter are shown in the figure below.

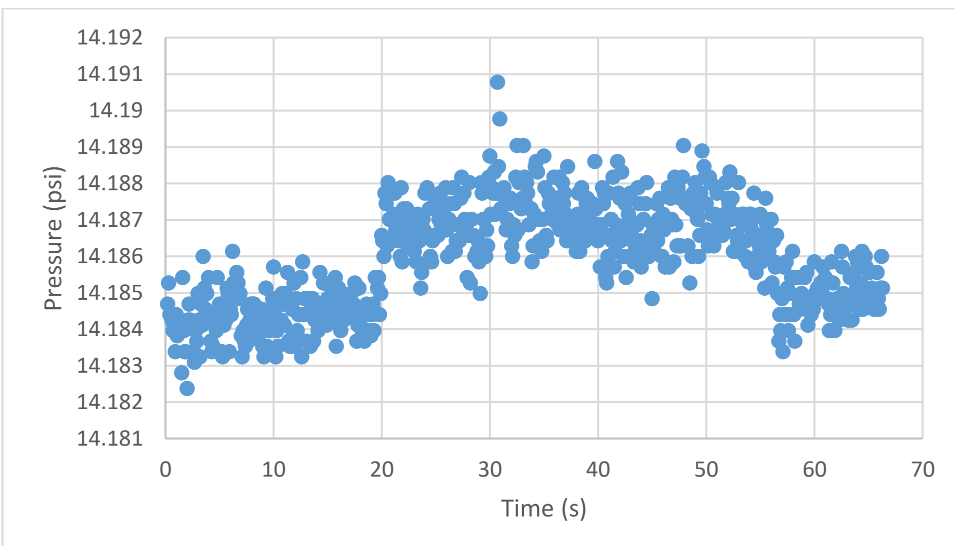


Figure 24: Internal Pressure of the Enclosure Without Filters

In the experiment for the figure above, the fans were turned on at about 20 seconds and then turned off at about 57 seconds. There is a sharp increase in the pressure inside the chamber which validates the concept of the positive pressure environment. To determine whether the addition of a filter would affect the positive pressure of the system the experiment was then re-run with filters placed over the input fans. The results of the experiment run with filters are shown in the figure below.

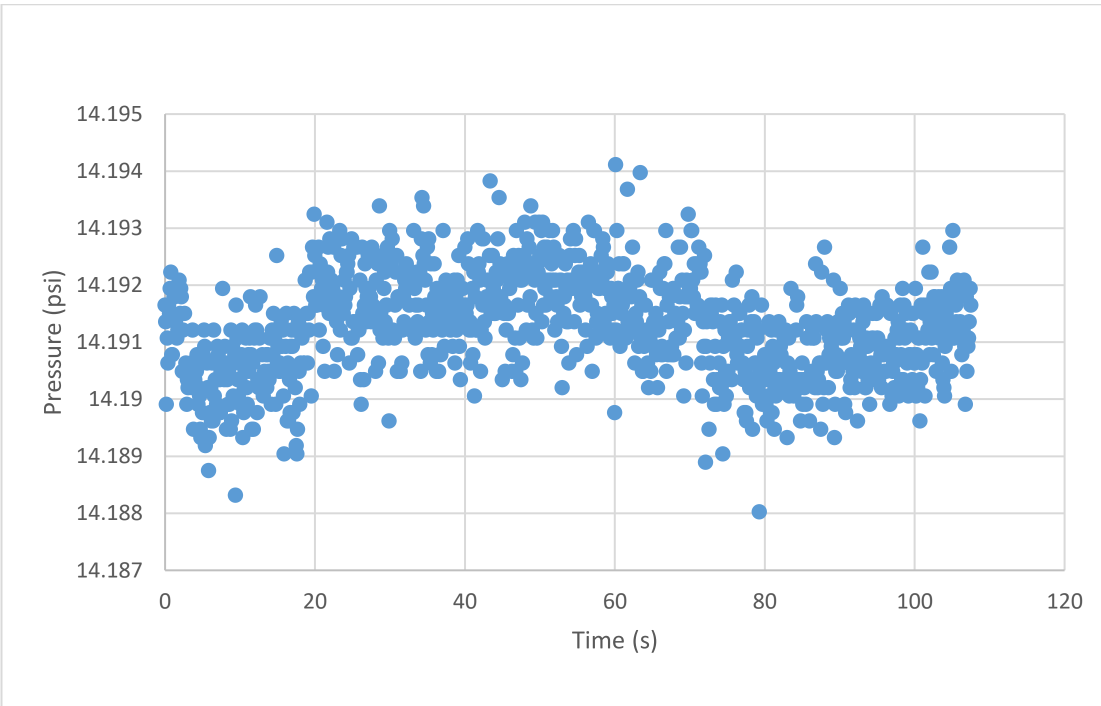


Figure 25: Internal Pressure of the Enclosure with Filters

In the experiment for the figure above, the fans were turned on at about 20 seconds and then turned off at about 75 seconds. While the pressure increase is not as sharp as the previous experiment, there is still a noticeable increase in the pressure while the fans were running. The effects of the positive pressure were also able to be noticeable felt around the air leaks in the system, pointing to the validity of the positive pressure concept.

Full scale experiments were then conducted on the full-size cover and briefcase prototype to verify the results of the previous experiments. For the full-size experiment, like the experimental setup, three twelve-volt DC fans were used where two were designated as input fans and one fan was designated as an output fan. A fog machine was also used to verify that besides the air from the input fans, all the excess air was escaping through the output fan and other air leaks and no other air and thus dust could enter the enclosure. The setup for the experiment is shown in the figure below.

Figure 26: Full Size Positive Pressure Experimental Setup

During the experiment when the fans were turned on, the validation of the positive pressure system was noticeably visible because the enclosure itself expanded as shown in the figure below. The observation was also confirmed by the fog machine blowing air out of the output fan as well as other air leaks. Since air was only exiting from the air leaks, no dust would be able to enter the enclosure. The experiments performed validate the initial design concepts so that the design is ready for use in the field.

Figure 27: Expanded Case Due to Positive Pressure

Chapter 5

Conclusions

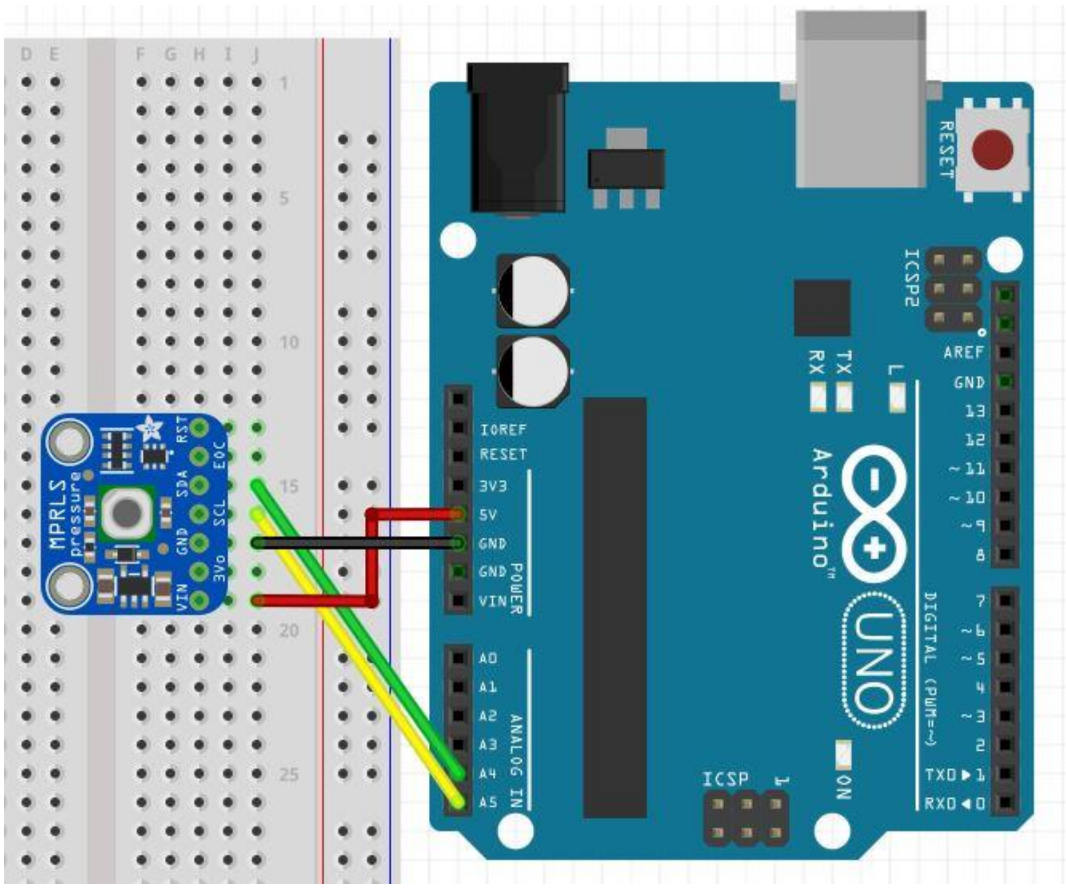
The purpose of this research project was to design and implement a working design of a collapsible case for a 3D printer that maintains temperature, pressure, and humidity. The final design of the 3D printer case is simple in nature and easy to set up and take down as well as light weight and easily collapses down to be stored within the 3D printer. The implementation of the design would allow for the Relief Bot printer to print higher quality prints which would give the doctors using the printer to print more sophisticated and accurate parts to help their patients as well as assist in teaching other doctors. The collapsible enclosure ensures that dust is kept out of the system, reducing the eventual failure of the electronics and prolonging the lifespan of the 3D printer. As with any design process, the last step is always to iterate the design process to make constant improvements. Future work could always be done to re-evaluate the decisions made for the final design as well as make modifications for new and adaptable situations.

Some possible future research would be to experiment with different gauge vinyl materials and assess their strength relative to other factors like weight, visibility, and ability to collapse into a small volume suitable for storage. Although the concept of overcurvature was discussed in the literature review, the design concept was not pursued due to its difficulty of implementation and high costs when creating prototype designs. Future research with more resources could explore the design possibility of overcurvature and its potential uses for collapsible cases.

Airflow experiments were performed to validate that the implemented design keeps out dust as well as maintains a positive pressure environment suitable for keeping out dust. While the literature review discusses methods for maintaining humidity and temperature, the Relief Bot printer was being redesigned so no tests for humidity and temperature could be done to optimize these parameters without the finished printer design and a functioning heated bed. Future work once the 3D printer design is completed would be to measure the ability of the fans to expel or maintain heat to maintain the optimum enclosure temperature for the highest quality 3D prints. Experiments with different salt solutions could also be done test how the system can minimize the relative humidity relative to the outside environment.

Appendix A

Arduino Schematic and Code for Pressure Sensor




```
/*!
 * @file mprls_simpletest.ino
 *
 * A basic test of the sensor with default settings
 *
 * Designed specifically to work with the MPRLS sensor from Adafruit
 * ----> https://www.adafruit.com/products/3965
 *
```

```
 * These sensors use I2C to communicate, 2 pins (SCL+SDA) are required
 * to interface with the breakout.
 *
 * Adafruit invests time and resources providing this open source code,
 * please support Adafruit and open-source hardware by purchasing
 * products from Adafruit!
 *
 * Written by Limor Fried/Ladyada for Adafruit Industries.
 *
 * MIT license, all text here must be included in any redistribution.
 *
 */

#include <Wire.h>
#include "Adafruit_MPRLS.h"

// You dont *need* a reset and EOC pin for most uses, so we set to -1 and don't connect
#define RESET_PIN  -1  // set to any GPIO pin # to hard-reset on begin()
#define EOC_PIN    -1  // set to any GPIO pin to read end-of-conversion by pin
Adafruit_MPRLS mpr = Adafruit_MPRLS(RESET_PIN, EOC_PIN);

void setup() {
  Serial.begin(115200);
```

```
  Serial.println("MPRLS Simple Test");
  if (! mpr.begin()) {
    Serial.println("Failed to communicate with MPRLS sensor, check wiring?");
  }
  Serial.println("Found MPRLS sensor");
}



void loop() {
  float pressure_hPa = mpr.readPressure();
   //Serial.print("Pressure (hPa): ");
   Serial.println(pressure_hPa);
  //Serial.print("Pressure (PSI): ");
  //Serial.println(pressure_hPa / 68.947572932);
  delay(100);
}
```

BIBLIOGRAPHY

ASHRAE. (2010). *Ventilation for Acceptable Indoor Air Quality Standard 62.1*. Atlanta, GA.

Berman, B. (2012). 3-D printing: The new industrial revolution. *Business Horizons*, *55*(2), 155–162. https://doi.org/10.1016/j.bushor.2011.11.003

Carneiro, O., Silva, A., & Gomes, R. (2015). Fused deposition modeling with polypropylene. *Materials and Design*, *83*, 768–776. https://doi.org/10.1016/j.matdes.2015.06.053

Chari, V. S., Venkatesh, P. R., Krupashankar, & Dinesh, V. (2018). Effect of processing parameters on FDM process. In *AIP Conference Proceedings* (Vol. 1943). https://doi.org/10.1063/1.5029637

Compton, B. G., Post, B. K., Duty, C. E., Love, L., & Kunc, V. (2017). Thermal analysis of additive manufacturing of large-scale thermoplastic polymer composites. *Additive Manufacturing*, *17*, 77–86. https://doi.org/10.1016/j.addma.2017.07.006

Dizon, J. R. C., Espera, A. H., Chen, Q., & Advincula, R. C. (2018). Mechanical characterization of 3D-printed polymers. *Additive Manufacturing*, *20*, 44–67. https://doi.org/10.1016/j.addma.2017.12.002

Dudte, L. H., Vouga, E., Tachi, T., & Mahadevan, L. (2016). Programming curvature using origami tessellations. *Nature Materials*, *15*(5), 583–588. https://doi.org/10.1038/nmat4540

Forney, C. F., & Brandl, D. G. (1992). Control of humidity in small-environment chambers with glycerol-water solutions. *Hort Technology*, *2*(1958), 52–54.

Gao, J. (2014). Effect of Dust Contamination. *Water*, 185–228. https://doi.org/10.1201/b15640-6

Gao, W., Zhang, Y., Ramanujan, D., Ramani, K., Chen, Y., Williams, C. B., … Zavattieri, P. D. (2015). The status, challenges, and future of additive manufacturing in engineering. *CAD Computer Aided Design*, *69*, 65–89. https://doi.org/10.1016/j.cad.2015.04.001

Guerrero-De-Mier, A., Espinosa, M. M., & Domínguez, M. (2015). Bricking: A New Slicing Method to Reduce Warping. *Procedia Engineering*, *132*, 126–131. https://doi.org/10.1016/j.proeng.2015.12.488

Halidi, S. N. A. M., & Abdullah, J. (2012). Moisture effects on the ABS used for Fused Deposition Modeling rapid prototyping machine. *Symposium on Humanities, Science and Engineering Research*, 839–843. https://doi.org/10.1109/SHUSER.2012.6268999

Kayfi, R., Ragab, D., & Tutunji, T. A. (2015). Mechatronic system design project: A 3D printer case study. *2015 IEEE Jordan Conference on Applied Electrical Engineering and Computing Technologies, AEECT 2015*, (December). https://doi.org/10.1109/AEECT.2015.7360570

Kean, T. A. (1995). *5469003*. USA.

Kellogg, M. S., & Krotts, D. B. (2002). *6494335B1*. USA.

Kelly, M. J., Boulton, W. R., Kukowski, J. A., Meieran, E. S., Pecht, M., Peeples, J. W., & Tummala, R. R. (1995). *Electronic manufacturing and packaging in Japan*. *North*.

Kerber, S., & Walton, W. D. (2003). *Characterizing Positive Pressure Ventilation using Computational Fluid Dynamics*.

Kietzmann, J., Pitt, L., & Berthon, P. (2015). Disruptions, decisions, and destinations: Enter the age of 3-D printing and additive manufacturing. *Business Horizons*, *58*(2), 209–215. https://doi.org/10.1016/j.bushor.2014.11.005

Kim, E., Shin, Y.-J., & Ahn, S.-H. (2016). The effects of moisture and temperature on the mechanical properties of additive manufacturing components: fused deposition modeling. *Rapid Prototyping Journal*, *22*(6), 887–894. https://doi.org/10.1108/RPJ-08-2015-0095

Kim, K.-S., Hahn, T., & Croman, R. (1989). The Effect of Cooling on Residual Stress in a Thermoplastic Composite. *Journal of Composite Technology and Research*, *11*(2), 47–52. Retrieved from https://compass.astm.org/DIGITAL_LIBRARY/JOURNALS/COMPTECH/PAGES/CTR10151J.htm

Lambert, K., Welch, S., & Merci, B. (2018). The Use of Positive Pressure Ventilation Fans During Firefighting Operations in Underground Stations: An Experimental Study. *Fire Technology*, *54*(3), 625–647. https://doi.org/10.1007/s10694-018-0700-8

Manufactur3D. (2018). How FDM/FFF 3D Printing Technology Works? Retrieved February 13, 2019, from https://manufactur3dmag.com/working-fdm-fff-3d-printing-technology/

Monzón, M. D., Ortega, Z., Martínez, A., & Ortega, F. (2014). Standardization in additive manufacturing: activities carried out by international organizations and projects. *International Journal of Advanced Manufacturing Technology*, *76*(5–8), 1111–1121. https://doi.org/10.1007/s00170-014-6334-1

Morsali, S., Soheil, D., Zhou, Z., Behroozfar, A., Qian, D., & Minary-Jolandan, M. (2017). Multi-physics simulation of metal printing at micro/nanoscale using meniscus-confined electrodeposition: Effect of environmental humidity. *Journal of Applied Physics*, *121*, 024903. https://doi.org/10.1063/1.4973622

Mouthuy, P. O., Coulombier, M., Pardoen, T., Raskin, J. P., & Jonas, A. M. (2012). Overcurvature describes the buckling and folding of rings from curved origami to foldable tents. *Nature Communications*, *3*, 1290–1298. https://doi.org/10.1038/ncomms2311

Mueller, B. (2012). Additive Manufacturing Technologies - Rapid Prototyping to Direct Digital Manufacturing. *Assembly Automation*, *32*(2). Retrieved from https://www.emeraldinsight.com/doi/full/10.1108/aa.2012.03332baa.010

Noll, J., & Cecala, A. (2015). Instituting a filtration/pressurization system to reduce dust concentrations in a control room at a mineral processing plant. *Mining Engineering*, *67*(12), 42–48. https://doi.org/10.1186/s40945-017-0033-9.Using

Peng, A., & Wang, Z. (2010). Researches into influence of process parameters on FDM parts precision. In *International Conference on Mechanical Engineering and Green Manufacturing 2010, MEGM 2010* (Vol. 34–35, pp. 338–343). Trans Tech Publications. https://doi.org/10.4028/www.scientific.net/AMM.34-35.338

Reis, P. M., López Jiménez, F., & Marthelot, J. (2015). Transforming architectures inspired by origami. *Proceedings of the National Academy of Sciences*, *112*(40), 12234–12235. https://doi.org/10.1073/pnas.1516974112

Solomon, M. E. (1951). Control of Humidity with Potassium Hydroxide , Sulphuric Acid , or other Solutions. *Bulletin of Entomological Research*, *42*(3), 543–554. https://doi.org/10.1017/S0007485300028947

Stokes, R. H., & Robinson, R. A. (1949). Standard Solutions for Humidity Control at 25° C. *Industrial & Engineering Chemistry*, *41*(9), 2013–2013. https://doi.org/10.1021/ie50477a041

Vornanen-Winqvist, C., Järvi, K., Toomla, S., Ahmed, K., Andersson, M. A., Mikkola, R., … Kurnitski, J. (2018). Ventilation positive pressure intervention effect on indoor air quality in a school building with moisture problems. *International Journal of Environmental Research and Public Health*, *15*(2). https://doi.org/10.3390/ijerph15020230

Wang, T. M., Xi, J. T., & Jin, Y. (2007). A model research for prototype warp deformation in the FDM process. *International Journal of Advanced Manufacturing Technology*, *33*(11–12), 1087–1096. https://doi.org/10.1007/s00170-006-0556-9

Williamson, J. B. ., Greenwood, J. A., & Harris, J. (1956). The influence of dust particles on the contact of solids. *Proceedings of the Royal Society of London. Series A. Mathematical and Physical Sciences*, *237*(1211), 560–573. https://doi.org/10.1098/rspa.1956.0197

Wolf, E. P., Craig, M. T., & McGuinness, E. (2015). *D733196S*. USA.

Wu, W. Z., Geng, P., Zhao, J., Zhang, Y., Rosen, D. W., & Zhang, H. B. (2014). Manufacture and thermal deformation analysis of semicrystalline polymer polyether ether ketone by 3D printing. *Materials Research Innovations*, *18*(5), 12–16. https://doi.org/10.1179/1432891714Z.000000000898

Young, J. F. (1967). Humidity control in the laboratory using salt solutions-a review. *Journal of Applied Chemistry*, *17*(9), 241–245. https://doi.org/10.1002/jctb.5010170901

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- Battery Density Research – Characterize, fabricate and test lithium fuel cells to improve density for lithium ion batteries used in electric vehicles
- Mechanical Properties Testing Lab – Test 3D printed shape memory alloys and analyze microstructure to determine mechanical properties
- Cardboard Chair – Design and build a collapsible chair made solely from cardboard, using no adhesives, and sized for college dorms

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BMW Mechanical Engineering Co-op – Greer, SC — January 2018 – May 2018

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- Assist with conducting a motion study to computationally improve stacker movements, as well as reduce vibration for faster and more accurate movement
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RA Resident Assistant – University Park, PA — August 2017 – December 2017

- Create a safe and inclusive environment, promote the personal and academic growth of others while also serving as a role model
- Communicate and resolve conflicts between residents and with fellow RA's
- Exercise rapid decision making in crisis situations

Soccer Referee – Hudson Valley, NY — March 2007 – Present

- Lead a team of referees in enforcing the game rules while also ensuring safety of all players
- Dispel conflicts between players, coaches, and parents who are often hostile
- Make quick, accurate decisions, call fouls and award penalty cards when necessary

Achievements

- Semester at Sea- Sail to13 destinations around the world while taking college courses
- ASME member and scholarship recipient
- Three Hierarchs, Modern Greek excellence, awarded by Archbishop of the Americas

Skills

Solidworks, MATLAB, FEA, CFD, Woodworking, Metalworking, Autodesk, Excel, Catia, Greek