Text'Tile'

BREE 495: Engineering Design 3

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Competition Entered: Creative Concious Awards

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Executive Summary:

Excess textile waste is an increasing global problem, as textiles in landfills generate negative environmental impact. One creative solution to mitigate textile waste is to repurpose recycled textiles into a usable product. This report explores a potential innovation in utilizing textile waste as a base material for acoustic panels. The Text'Tile', seeks to find a sustainable way of utilizing a binding agent in addition to shredded textiles in such a way that promotes sound absorbing qualities. Two different prototypes were generated: silicone composite and fabric stiffener composite. Out of the prototypes, fabric stiffener combined with shredded textiles was found to be an incredibly effective sound absorbing material, having a sound absorption coefficient between an ideal range of 0.8-1. Further optimizations for large scale production must be considered, such as downstream processing and code requirements that may impact future design. However, this experimental design has proven that there is a promising future for utilizing recycled textiles as newly repurposed products.

1. Introduction

Excess textile waste has escalated to a height of serious concern over the last few years. A fast-fashion culture of buying cheaply-made clothes for a significantly lower price has consumers discarding relatively new garments after short periods of use. Textile recycling is either relatively uncommon or non-existent in many locations around the world. This being said, large volumes of discarded garments are sent to landfills rather than seeing the proper post-consumer recycling necessary. Once they are sent to a landfill, the synthetic fibers in many of today's clothes degrade slowly over time and release toxic chemicals and pollutants into the environment. As the amount of clothing in landfills is only increasing, it has become imperative to find creative, engineering solutions to mitigate textile waste.

Extensive research has concluded that one of the most efficient ways to mitigate textile waste is to repurpose the fibers into a usable product. By turning this waste into a usable product, it gets a new life away from sitting in a landfill. Out of the variety of possible products that can be created from recycled textiles, one promising area of focus is developing acoustic panels. Acoustic panels are porous boards typically made out of hard surfaces or foams that help to absorb and diffuse sound in homes and buildings. Acoustic panels help to create a more comfortable environment for building inhabitants and can also be visually enhancing to the location that they are placed.
Working closely with our mentor, it was decided that recycled textiles have great potential in applications for acoustics. We hypothesized that due to the long nature of textile fibers that these fibers may act positively as sound distributors and as absorbing agents.

Our design goal was to research, prototype, and optimize an acoustic panel, called the Text'Tile', made from a composite of recycled textiles and a fabric-stiffening binding agent. This report will highlight the initial analysis and specifications that were needed for panel fabrication as well as the stages involved in prototyping the first series of panels with different binding agents. Once prototyping was concluded, we conducted a series of acoustical tests to determine the prototypes' absorption coefficients to ascertain its effectiveness in sound absorption. After testing, design optimizations and future considerations were noted and explored in the context of future fabrication in a production setting. Lastly, we will conclude our findings and the overall potential and success of the Text'Tile'.

2. Analysis and Specifications

Sound absorbers are usually categorized into the following sections depending its primary absorption mechanism:

- Porous absorbers - its geometry and the porous material's acoustic properties
- Helmholtz resonators - its geometry
- Panel resonators - its geometry and panel's structural vibration properties

(Muehleisen, 2007).

All materials must be taken apart, shredded down, and mixed together to accommodate for a large variety of waste textiles obtained a second-hand store. For this reason, a porous absorbers is the best option. The short fibers would allow a lot of flexibility in how porous we would like to make them.

Porous absorbers could be further categorized as *open* cell or *closed* cell. In *closed* cell absorbers, such as foams, heat conduction is a major contributor and effects the sound absorption. However, cells in waste textile absorbers will be *open* thus are unaffected (Ingard, 1997). According to Professor Mongeau, sound absorption coefficient is one of the most important characteristics of a sound panel. All commercialized acoustic panels are tested; this value is indicative of how well a specific frequency is absorbed by a material. Further physical and mathematical analysis can be found in *Section 4.2 Acoustic testing.*

It is assumed that the acoustic panels will be installed in hallways that experience lots of human traffic. For example, in a typical hallway in the McConnell Engineering building in the downtown campus, there will peaks of high traffic in between classes. In large, open spaces such as those, echoing is a concern. In an interview with Professor Mongeau, he explained that a true echo, is the reflection of a sound (2016). In larger spaces, it is more obvious since the delay between the initial sound and the reflected sound is longer. Furthermore, to accommodate for busy hallways, the panels should be flexible to the absorption of a wide range of frequencies.

Figure 1 below shows an initial prototype drawing done in AutoCAD. Figure 2 below shows conceptualized prototypes using different types of materials:

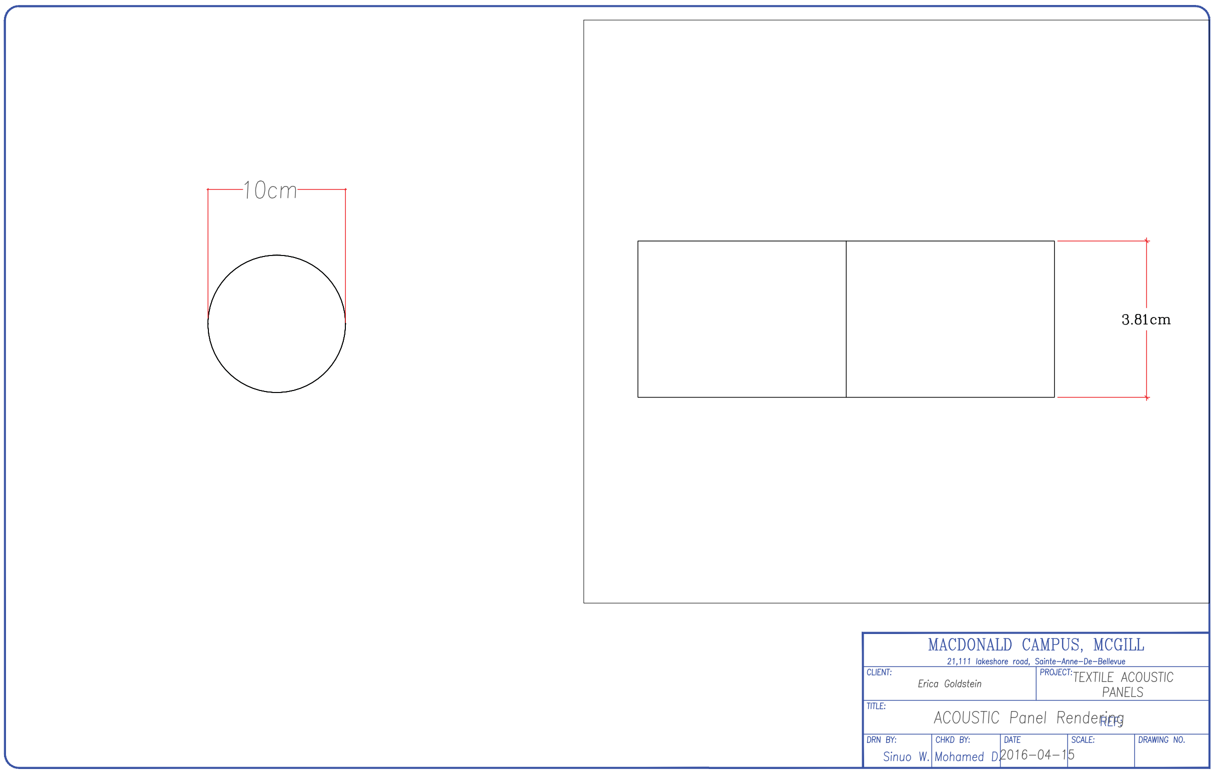


Figure 1: Prototype drawing and dimensions

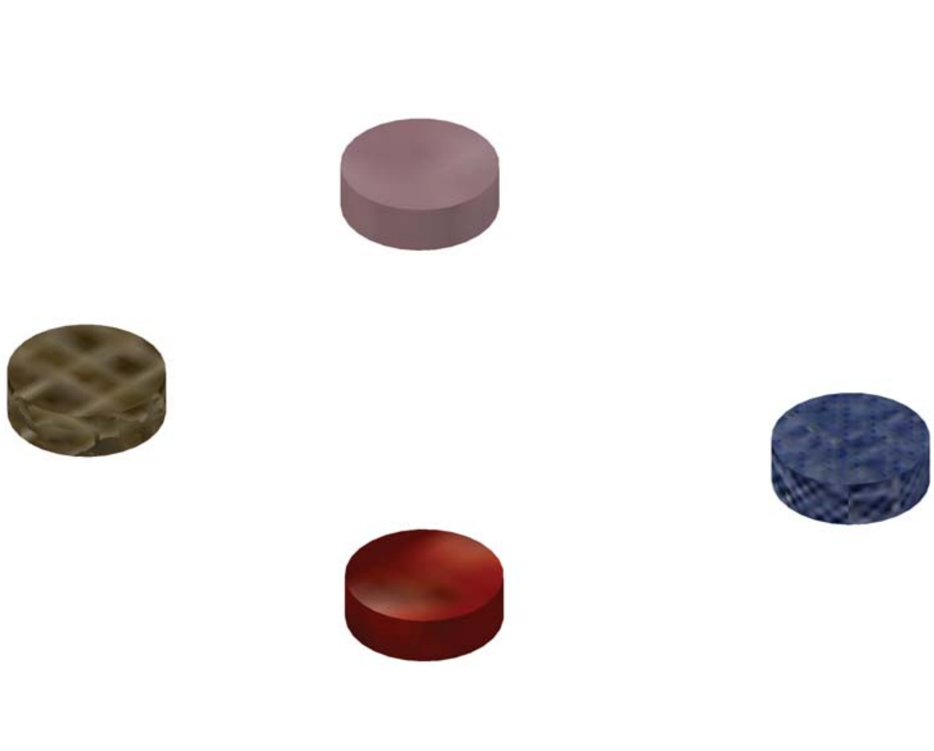


Figure 2: Conceptualized prototypes with different materials

3. Prototyping

With the research collected over the course of Design 2 in addition to our desired specifications and requirements, prototyping could then begin.

3.1 Materials:

- Shredded textiles
- 236 mL of Modge Podge Stiffy
- 74.75 mL of Silicone Sealant
- Mixing bowl
- 2 plastic Tupperware containers (V = 0.00304944 m^3)
- Baking dish
- Exacto knife
- Weights

3.2 Fabrication Procedure:

Over the course of the semester, three samples were fabricated. The first round of fabrication generated one panel combined with fabric stiffener and one panel combined with silicone. The second round of fabrication generated one final panel combined with fabric stiffener.

3.3 Shredding

The first step in fabricating the acoustic panel prototypes was to shred and deform various pieces of clothing. Clothing was selected by color, in order to achieve a satisfactory visual effect once combined. The articles of clothing utilized for the prototypes consisted of used t-shirts and socks that would have otherwise been donated to clothing collection facilities. Each shirt shredded was composed of various fibers including cotton, nylon, wool, polyester, and rayon. However, the contents were not noted because in the theoretical fabrication of a large-scale operation would disregard fabric composition and sort fabrics by color. The general method for shredding consisted of taking fabric shear and making a first initial cut that would create loose, severed fibers. These fibers were then pulled in order to begin deconstructing the tightly woven fabric matrix. After a few of these small, initial fibers were pulled, the larger sample would begin to further and more easily pull apart. The fibers were continually pulled until there were no remaining tightly-woven sections of the piece being deconstructed. Occasionally, a knot would result in the fiber pulling. Simply cutting the knot would circumvent this issue making the fibers easy to pull once again. The final result of the pulled fibers resembled thread but with significant crimping. The texture of these fibers was incredibly soft and springy. For thicker fibers and some more tightly woven fibers, such as wool and cotton, the samples were rolled tightly and then sheared off in small pieces by the fabric shears. These pieces are slightly rougher and larger in size and texture than the deconstructed fibers, but add an appealing visual appearance when combined with the pulled fibers. The shredding process was the most time-intensive and was the bulk of time spent prototyping.

3.4 Mixing

The first step of mixing was placing a large volume of shredded textiles into a mixing bowl. Using the fabric shears, the textiles were coarsely chopped to shorten the long fibers. The shortened fibers were then tossed together and mixed in order to achieve a better-marbled appearance for visual purposes. Once appearance of the mixed textiles was achieved, the textile mixture was divided amongst two Tupperware containers, each with a volume of 0.00304944 m^3. The textiles were loosely placed in each container, but filled the container to the top surface. Once divided, each mold was then separately mixed with its respective binding agent. First, combination of fabric stiffener and textile was mixed. The entire volume of 236 mL was utilized. The mixture was tossed similarly to the mixing of the fibers, ensuring that the solution was well distributed over the fibers and covering all available surface area of the fibers. Once thoroughly mixed, the solution was placed back into its Tupperware container. The mixing bowl was then washed to remove any remnants of the fabric stiffener would be removed. After this step, the silicone mixture was then created. Roughly ¼ of the silicone sealant was utilized, resulting at around 74.75 mL. After it was thoroughly mixed, the solution was placed back into its Tupperware container.

3.5 Molding

After mixing, the samples needed to be molded and compressed. It was necessary to make the panels relatively dense and compact so that they would be formed into a thickness between 1-2 inches. The Tupperware containers utilized for the first round of molding were selected since they nested into each other. For this reason, the fabric stiffener solution was placed underneath the silicone solution so that the bottom of the top Tupperware container would create a flat top. Additionally, any weight used to compress the mold would then work on both samples. Therefore, the final result of the molds had two nested Tupperware with weight and a cylinder block resting on top. The added weight caused excess mold to secrete upwards from the sides of the molds. To drain some of the excess liquid, holes were poked in the sides of the Tupperware using an exacto knife. The holes also allowed for added airflow for drying.

3.6 Curing

Once the initial excess liquid was drained, the molds were left to cure with the added weight for 48 hours. After the first 24 hours, the molds were pushed and drained of excess liquid a second time. After 48 hours, the weights were removed from the top of molds. The Tupperware containers were then separated and cut to remove the prototype samples. The samples were then placed by a window and continued to dry over the next two days. The samples cured for approximately 4 days in total, with 2 days in containers and 2 days out of the containers.

3.7 Initial Observations

Each of the two samples had a significantly different texture, weight, and overall composition. The panel made from textile and fabric stiffener exhibited a lighter feel, rougher texture, and more porous appearance. Although not as hard as the baseline panel, the fabric stiffener panel was much harder when compared to its silicone counterpart. The silicone panel was significantly denser than the fabric stiffener and had a much smoother texture to the touch. The composition felt less like fibers and more similar to rubber, which is expected considering it is a silicone sealant composite. It was also significantly denser than the fabric stiffener composite. Although each sample was compressed by enough weight for it to be at roughly a 1-inch thickness, the fabric stiffener panel achieved a thickness closer to 1.5 inches and the silicone panel maintained a thickness closer to or even less than 1 inch. It should be noted that these initial observations of thickness were not exact measurements, but comparisons to the mold when it was first fabricated.

The final prototypes can be seen in Figures 3 & 4. More pictures of each prototype can be seen in *Appendix 3: Additional Images of Prototypes*

Figure 3: Fabric stiffener composite prototype

Figure 4: Silicone composite prototype

3.8 Final Prototype Dimensions:

The prototype dimensions (diameters and thickness) are determined by taking the average of several measurements obtained using a dial caliper. These values are originally in imperial units but have all been converted to SI units. The raw empirical data can be seen in *Appendix 1 Table of prototype measurements and calculations.*

Table 1 shows several dimensions obtained through calculations of the measured data After determining the dimensions the volume is determined using the equation shown below:

Table 1: Average sample dimensions

	Fabric Stiffener	Silicone
Diameter (cm)	10.17	8.44
Radius (cm)	5.08	4.21
Thickness (cm)	3.16	2.79
Volume (cm^3)	256.19	155.35

$$V = \pi r^2 h [cm^3] \qquad \text{(i) Volume equation}$$

Where r is the radius [cm] and h is the height [cm]

4. Testing

4.1 Economic Analysis

A single panel was made with one bottle of Modge Podge Stiffy purchased for $10.99 or around one bottle of Silicone Sealant purchased for $5.99. The waste textiles were obtained for free since it was rejected by second-hand clothing stores. Considering the hefty price of $10.99 for a single panel that is palm-sized. The final product could become unfeasible due to the price. However, it must be taken into consideration that the epoxies were bought at retail price. The epoxies chosen are very commonly used in the construction and textile industry. Should the product become industrialized, the wholesale price would much more economical.

4.2 Failure Modes

Below are two failure modes that were considered.

4.2.1 Top-down Failure Mode

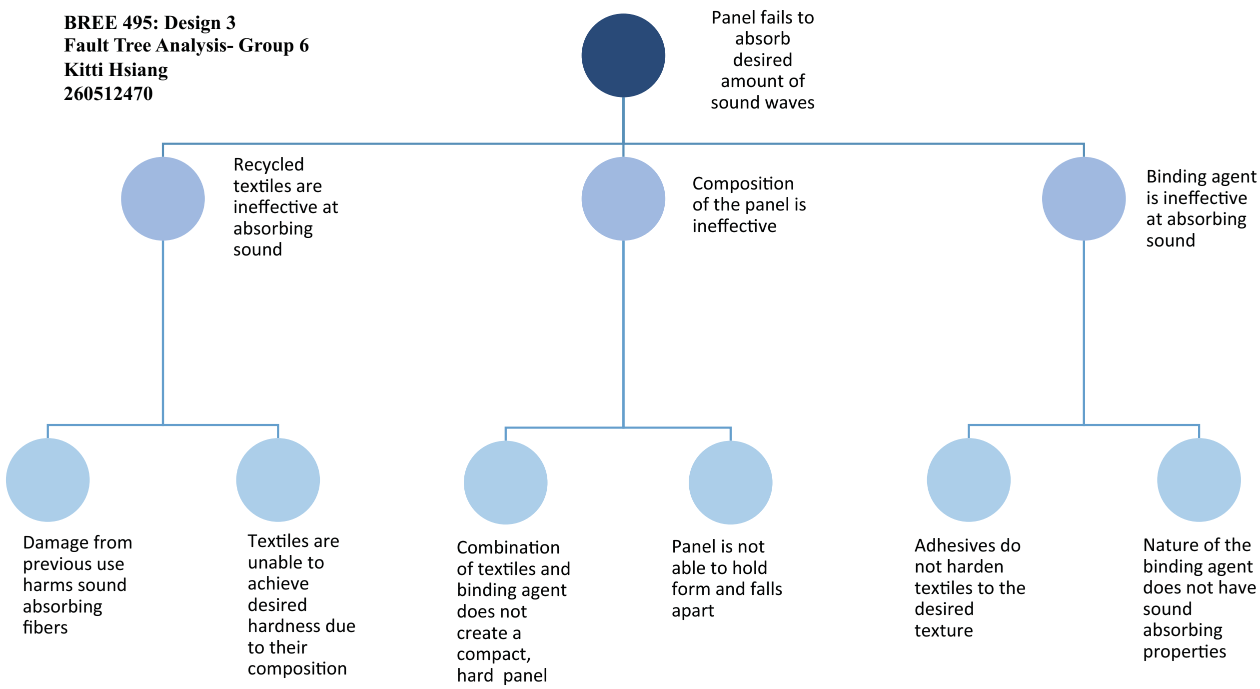


Figure 5: Top-down Failure Mode

Figure 5 shows a Fault Tree Analysis which access possible failure top down. It considers failure by the different possible failing consequences; then considers corresponding reasons that could cause said failure.

4.2.2 Bottom-up failure mode

Process Step	Potential Failure Mode	Potential Failure Effect	SEV	Potential Causes	OCC	DET	RPN (SEV*OCC* DET)	Action Recommended
Acoustic panel	Panels do not achieve acoustic standards	Client rejects project	7	Binding agent of panel disrupts pores	4	10	280	It will be recommended that all processes and prototypes are tested according to appropriate standards to minimize chances of failure.
	Panels don't meet fire protection standards	Panels not fulfill building standards and cannot be used	9	The textile's properties or sources are unknown	3	10	270	
	Textiles are not suited for acoustic panels	Original problem becomes irrelevant	7	The variability in textile properties are too large, the source of textile is unknown	8	9	504	
	The binding agent fails to bind textile, or does not accommodate for porosity	Textiles will not have acoustic properties	9	The nature of the binding agent is unsuitable for this project	2	10	180	

Figure 6: Bottom-up Failure Mode

The bottom-up analysis is an inductive approach, which considers each component that could cause failure individually. The potential failure's severity is then evaluated so appropriate recommendations could be made. This encourages people to think more comprehensively before attempting to prototype.

4.3 Acoustic Test

Professor Luc Mongeau, a specialist in acoustics at McGill University, recommended the standard wave test to determine the prototypes' absorption coefficient. This test is a universal test and uses the same methodology as that *of ASTM C384-04 Standard Test Method for Impedance and Absorption of Acoustical Materials by Impedance Tube Method* (ASTM, 2011).

As a sound wave hits a sound absorbing material, the sound wave travels into and is trapped inside the panels' pores. The sound is "absorbed" when the wave energy causes vibrations within the pore and becomes dissipated as heat.

The acoustic coefficient of an absorbing material ranges between zero and one – one being the maximum. It is the ratio of absorbed ratio to the incident energy. This method is very suitable for the available prototypes since it only requires a small test sample (Russell, 2007).

4.4 Theory

In a standing wave test, there is a speaker and amplifier at one end and the sample at the opposite end with a standing wave tube that connects the two. This is shown in Figure 7 below:

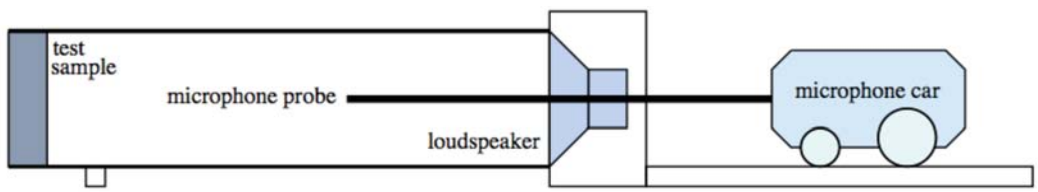


Figure 7: Typical Standing Wave Test Setup (Russell, 1997)

The speaker produces a sound wave (sine wave) of a predetermined frequency and is amplified by the amplifier. The incident sound wave travels down the tube and hits the absorbing surface (prototype). The incident wave will produce sound waves of certain amplitude. If the test sample were somewhat sound absorbing, the reflected wave would be of different amplitude than the incident wave. The phase interference of the two waves would form a standing wave inside the tube. Through a series of calculations after determining the minimum and maximum amplitude for each frequency, the absorption ratio is found.

4.5 Materials:

- Test samples
- NEXUS Charge Amplifier - Type 2692-A
- 4939 - ¼-inch free-field microphone, 4 Hz to 100 kHz, 200V polarization
- NI 9215±10 V, Simultaneous Analog Input
- LabVIEW Program
- Metal, rigid backing
- Sticky Tack
- Cables

4.6 Procedure

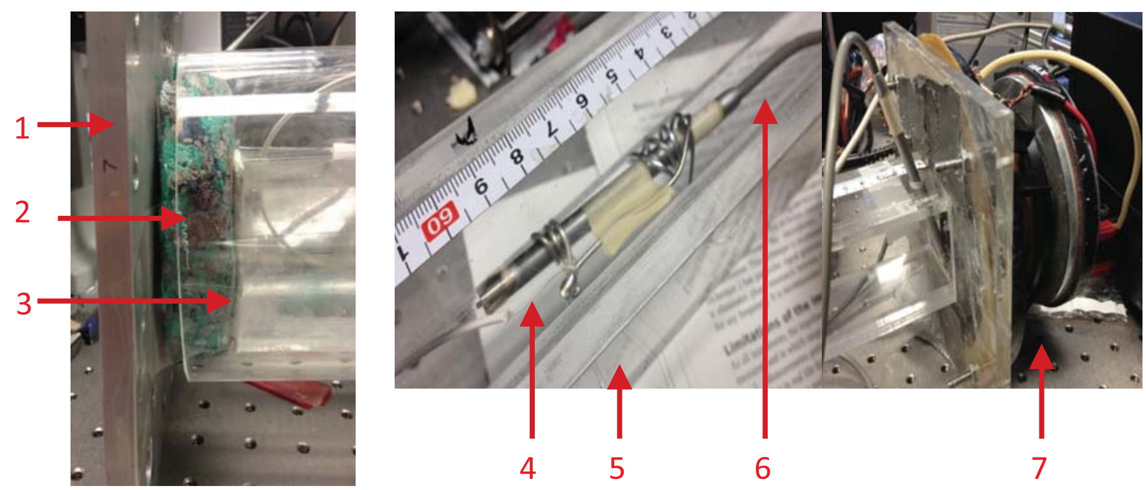
Prior to testing, assure that the speaker, amplifier, microphone, analogue, and computer program are properly working. To do so, produce a sound of a certain frequency and make sure that the LabVIEW Oscilloscope produces a graph that confirms the predetermined frequency.

The test sample must be tightly fitted to the end of the tube. The sample would preferably fit perfectly or be cut down to a size such that it could perfectly inside the tube. In cases where the sample cannot be cut without significantly damaging it, put putty over the tube channel's end rim and press the prototype tightly onto the end to ensure proper sealing to minimize sound wave leakage. To ensure accurate measurements from the microphone, a rigid backing behind the sample is placed behind the sample to minimize the loss of sound waves that transmit through the sample material.

The microphone car is prepared by attaching two cables at either end of the microphone car and threading one cable through each hole. This allows the microphone car to easily move up and down the channel. The mobility of the microphone car enables the detection of the node and antinodes; since in a sine wave, a node and antinode are always one-quarter wavelength apart.

With a predetermined frequency, allow the speaker to produce a continuous sound. Starting with the microphone car up against (but not touching) the test sample, move the microphone slowly away from the sample until a maximum or minimum value is seen. These values represent the antinode and node respectively. Adjust the y-axis in the LabVIEW window accordingly to get a more accurate reading of the amplitude. Repeat the previous step to find the other extreme. Then, with a different frequency, find the maximum and minimum amplitudes. Figure 8 below is an annotated test set up:

Standing Wave Test - Setup



Legend:
1. Rigid backing
2. Testing sample
3. Fitted tube and tack
4: Microphone car
5. Tube channel
6. Microphone car cable
7. Sound source

Figure 8: Annotated Test Setup

5. Results and Discussion

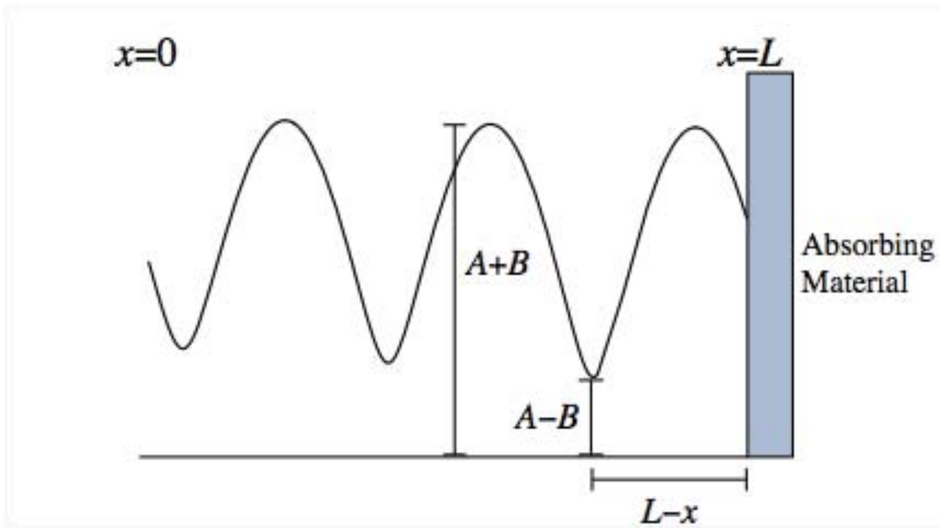


Figure 9: Standing wave graph (Russell, 1997)

Figure 9 above shows the standing wave created by the incident and reflected wave. A+B is the maximum where the two waves are additive and A-B is the minimum point when the two waves are subtractive in nature. With the A+B and A-B values from the LabVIEW graph, the sine wave ration and absorption coefficient could easily be determined using the two equations below:

$$SWR = \frac{A+B}{A-B}$$ (ii)Standing Wave Ratio Equation

$$\alpha = \frac{(SWR-1)^2}{(SWR+1)^2}$$ (iii) Absorption Coefficient Equation

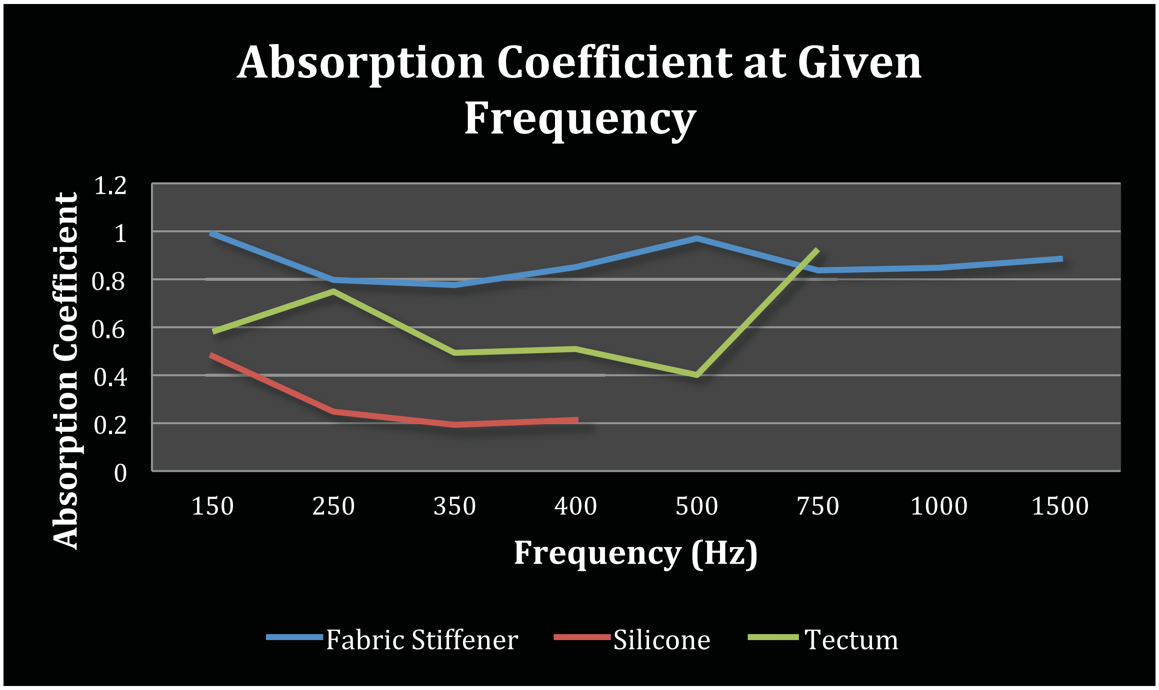


Figure 10: Absorption Coefficient of Prototypes at various frequencies

Figure 10 above shows the absorption coefficient of all three types of samples tested at various frequencies. A line graph allows for easy comparison between the different samples. It also highlights the trend regarding how the absorption coefficient changes in one sample with different frequencies.

5.1 Baseline Panel Performance

Our baseline panel, Tectum, performed at satisfactory levels of absorption as expected. It had mediocre performance in the frequency range of 100-500 Hz, fluctuating between absorption coefficient values of 0.4-0.8. However, once the frequencies increased past 500 Hz, the line trend began to display a linear increase towards a frequency of 750 Hz. Based on this trend, one would think the absorption levels would also continue to increase, however since each frequency reacts differently dependent of each other, it cannot be assumed that performance would continually improve. To understand further the reactions of Tectum at higher frequencies, further testing would need to be implemented or consulting the Tectum material specification values would be required.

5.2 Fabric Stiffener Composite Panel Performance

Between the two panels, the fabric stiffener composite presented the most successful absorption coefficient values. Absorption coefficients ranged between just below 0.8-1 between 100-1500 Hz. Given that extremely successful absorption coefficients are considered to be greater than 0.8, this shows promising results from the collected data. Having high values such as this indicates that there is potential for further fabrication of an acoustic panel derived from recycled textiles and a binding agent that acts similarly or better than craft-store fabric stiffener. The success of the fabric stiffener can be largely attributed to its increased porosity in comparison to the silicone composite panel. Increased porosity allows for more travel for sound waves and therefore increased absorption. The texture of the final fabric stiffener panel also more closely resembled the baseline panel, where it felt closer to a textile-cement board as opposed to a piece of rubber, like the silicone. Testing at higher frequencies between 1,500-3,000 Hz will be a critical factor to determine the true success of the fabric stiffener composite panel. It is possible that the panel will have a lesser performance than the tectum at higher frequencies, but ideally the absorption coefficient would remain in the ideal range of 0.8-1.

5.3 Silicone Composite Panel Performance

The prototype fabricated with silicone proved to be the least successful of the two prototypes. When compared to the baseline panel, the silicone absorption coefficient values continually decreased as frequency increased. Even at a frequency of 150 Hz, its frequency with the highest recorded absorption coefficient, the absorption coefficient was reported to be only around 0.49. An absorption coefficient this low would be unacceptable for large-scale fabrication. From 250-400 Hz, this silicone panel experiences roughly an average absorption coefficient of 0.2 Given that porosity is the most critical factor to determine the success of an acoustic panel, it was concluded that the silicone panel offered little porosity and therefore reflected the sound being sent towards it rather than absorbing sound. The unique construct of silicone bound more or less around the textile fibers, making it a more heterogeneous silicone substance while the fabric stiffener panel absorbed the adhesive being added to it. Since the silicone panel performed so poorly, it would not be recommended to fabricate additional prototypes to test at larger frequencies.

6. Optimization

Once the prototypes were fabricated and tested, it became obvious that there are certain qualities that need to be addressed and improved upon if the prototypes were ever produced on a large scale. These optimizations are critical for further improvement. Given that the fabric stiffener prototype had superior absorption coefficients compared to the silicon prototyping, any optimizations described will be exclusively for the fabric stiffener model.

6.1 Shredding

The longest and most tedious aspect of prototyping was shredding. Since the goal for the design was to obtain a deconstructed, fibrous material, shredding by hand was incredibly time consuming. Since it was an essential step in developing the final appearance and success of the prototype, faster methods of shredding must be ascertained for future developments. In a large scale scenario, utilizing a large-scale industrial shredding would likely be an acceptable technology to shred multiple types of textiles fabrics. However, it would be recommended to use a shredder that is specifically designed to achieve a thinner and more fibrous mixture, similar to the consistency of the first panel prototype.

6.2 Less Binding Agent

Initially, the first fabric stiffener prototype was incredibly saturated. It was necessary to drain excess glue continually for the first hours of drying in order to facilitate the drying process. It is suggested that for large-scale production, a further experiment needs to be conducted to determine the ideal ratio of binding agent to textile. Such an experiment could resemble keeping a constant volume of material, and testing varying binding-agent volumes to find the optimal ratio. By reducing the amount of binding agent, a variety of purposes will be served. First, less binding agent will facilitate faster drying times since there will be less liquid to remove. This will decrease the fabrication period, which can help to optimize production as well. Second, less binding agent needed will decrease overall cost. Since less binding agent is needed per volume, the amount of binding agent available will last for a longer period of time. This means reduced costs on purchasing binding agent, which proves to be one of the more expensive costs to the panel.

6.3 Forced Convection for Curing

Another optimization necessary to promote increased curing time would be to add forced convention air during the drying period. For prototyping, the fabric stiffener panels were air dried. This process took a minimum of 72 hours to develop a panel solid enough to be moved and held. For production purposes, this is unideal for it would take incredibly long to generate product. In a large scale environment, or for the next prototype, forced air should be run over the panels from various angles to ensure uniform drying. Trails should be conducted with both cold and hot air to ascertain which temperature is more effective. Once this has been decided, separate experiments can be conducted to determine not only which exact temperature is the most cost effective. Extreme temperatures will require more energy, which will be a greater cost for the facility. Finding an exact temperature will ensure an effective drying process but one that is also affordable.

6.4 Variable Types of Textile

In the ideal production scenario, the textiles used for a panel would be made up of a variety of fabrics, which are unknown in the production line. For the initial experiments, the textiles shredded were of known materials, such as nylon, cotton, spandex, and wool. Further prototypes that consist of a wider variety of fabrics should be made in order to test a more averages absorption coefficient.

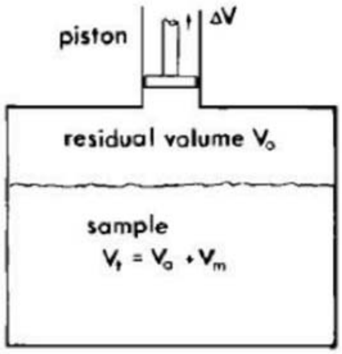
6.5 Bio-based Binding Agents

Although the prototypes utilized standard fabric stiffener, a bio-based binding agent would in reality be the most ideal adhesive for the acoustical panel. Sustainability is a critical factor for the acoustic panel. Since the properties of the fabric stiffener are relatively unknown, a bio-based agent of more sustainable origin would ensure a more positive life cycle of the product.

6.6 Future Testing

6.6.1 Microstructure Property Testing

Porosity is a microstructural property that should be tested in the future to better understand the prototypes. Microstructural properties are geometries describing how sound wave and the materials interact. These interactions determine the material's bulk properties (Muehleinsen, 2007). Porosity is defined as the ratio between the void volume and total volume. This would be hard to accurately test, especially in open cell absorbers such as these, because fiber connections are random and it’s hard to determine which ones are actually open. The suggested method is through the use of thermodynamics and Boyles law: By placing the sample in a chamber, and compress the volume, Boyles law states that internal pressure would increase (Muehleisen, 2007). The change is denoted in the figure below:



$$V_0 + V_t = -\frac{P_0 + \Delta P}{\Delta P} \Delta V$$

Figure 11: (Muehleisen, 2007)

6.6.2 Mechanical Property Testing

Although the acoustical properties were tested and observed, no mechanical properties were tested and obtained. Mechanical properties to be tested include but are not limited to elongation, hardness, deformation, density, and weight. These tests can be achieved by standard measurements and utilizing machinery such as a Universal Testing Machine. All the measurements taken should abide by ASABE standards and should be tested multiple times to obtain a standard average of values.

6.6.3 Acoustics at Higher Frequencies

With the machinery utilized for testing, a frequency of 1500 Hz was the highest frequency available for testing. Realistically, most buildings will experience frequency variations anywhere between 100-3,000 Hz. More advanced technology able to test at higher frequencies should be utilized to determine the panel's absorption coefficient between 1,500-3,000 Hz. Additionally, panels of varying thicknesses should be created and also tested, for thickness will influence the absorption coefficient. Once a more consistently uniform panel is produced, a more accurate representation of the absorption coefficient between the desired range of 100-3,000 Hz can be ascertained.

6.7 Building Code Requirements

Depending on the use of the panel will determine added factors that may be required of it. Whether or not a panel is placed in large building or residential environment will indicate added safety properties that need to be added. According to our mentor, the main concern in building code requirements is fire resistance. For residential buildings, added fire resistance properties are not necessary in panel construction. However, if placed in a large or public building, fire resistance properties are a necessity. To achieve a fire-resistant surface, the panel may need to either be fabricated with a fire-resistance fiber or dipped in a fire resistance coating.

6.8 Downstream Processing and Recycling

Another important area that must be researched is the downstream processing and recycling of the Text'Tile'. Given that the project was founded around finding a sustainable alternative to discarding textile waste, whatever product that is developed must follow sustainability principles as well. Therefore, further research must be completed into the areas of sourcing and recycling after it's given life. A critical aspect in this process includes the binding agent that is necessary to hold the panel together. Understanding the environmental implications of this binding agent as well as its downstream processing impact will help researchers to determine its recyclability as well as any necessary methods that are needed to dispose of the product if recycling is not possible. Additionally, sustainable processing must be attempted and observed, for if massive amounts of energy are required for panel fabrication, alternative methods must be found. Utilizing clean energy from solar panels or wind turbines is ideal and should be used if applicable.

7. Conclusion

Through research, prototyping, and testing it was determined that the fabric stiffener composite panel demonstrates great potential to be further developed as an acoustic panel. Consistently positive performance at a large range of frequencies and high absorption coefficients only justify its possibility. Although promising further acoustical, mechanical, and thermal testing must occur in order to ascertain the exact material requirements for an efficient and cost effective product. Additionally, future production optimizations must be considered and put into practice in order to improve upon the given prototype.

Many of these optimizations, which include factors such as downstream processing and recycling, large scale manufacturing, and inclusion of various textiles must be considered. The efficient mechanization of the fabric pre-processing would allow for rapid growth in scale of manufacturing. If the scale multiplies, addition of new and different materials would cause less change in the overall quality thus creating a positively reinforcing loop that promotes growth. The textile industry is a large net weaving together different stakeholders. The ability to repurpose waste textiles would ameliorate the increasing concerns due to landfill problems.

8 Works Cited

ASTM C384-04(2011), Standard Test Method for Impedance and Absorption of Acoustical Materials by Impedance Tube Method, ASTM International, West Conshohocken, PA, 2011, www.astm.org

Ingard, K. 1994. Notes on sound absorption technology. Noise Control Foundation, Poughkeepsie, NY.

Mongeau, L. 2016.

Muehleisen, R. 2007. Measurement of the Acoustic Properties of Acoustic Absorbers.

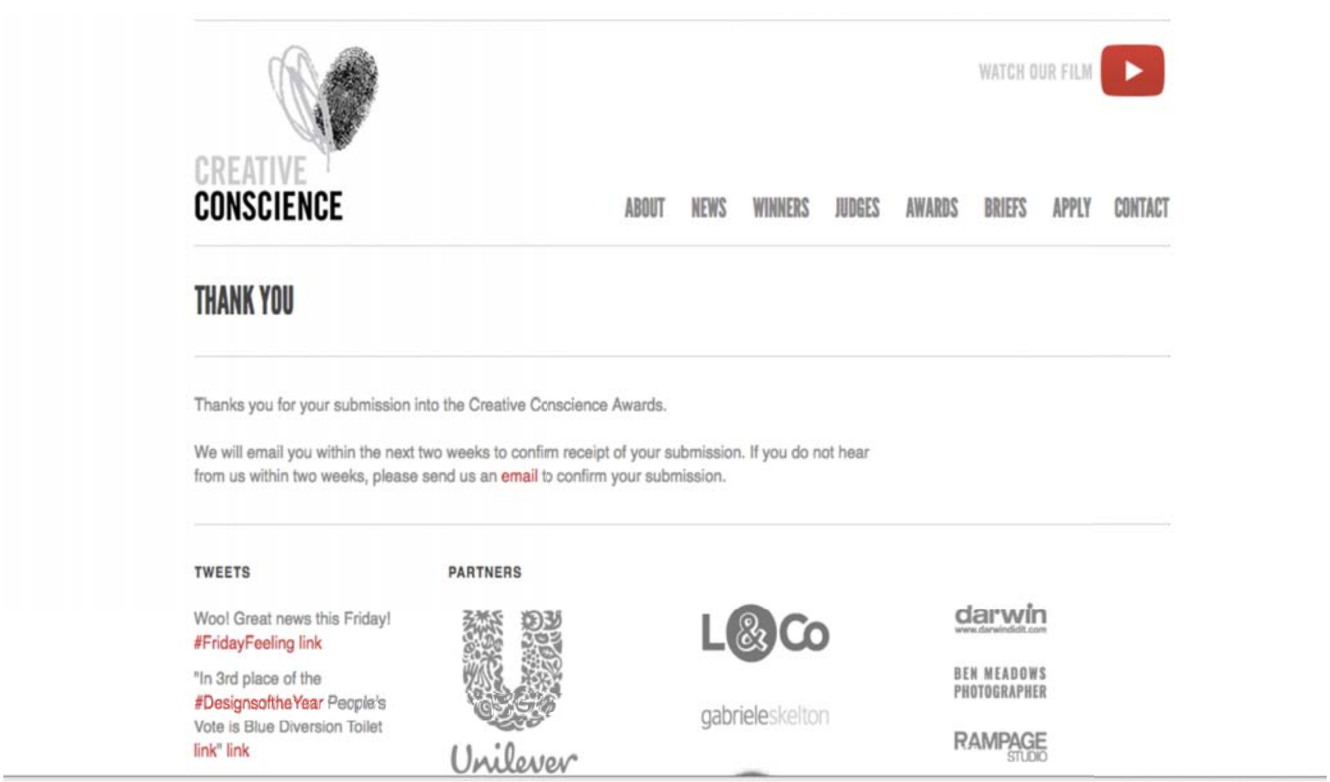
Russel DA. Absorption Coefficient and Impedance. Science and Mathematics Department, GMI Engineering and Management Institute Flint, MI, 48504, 1997

9. Appendices

Appendix 1 Table of prototype measurements and calculations

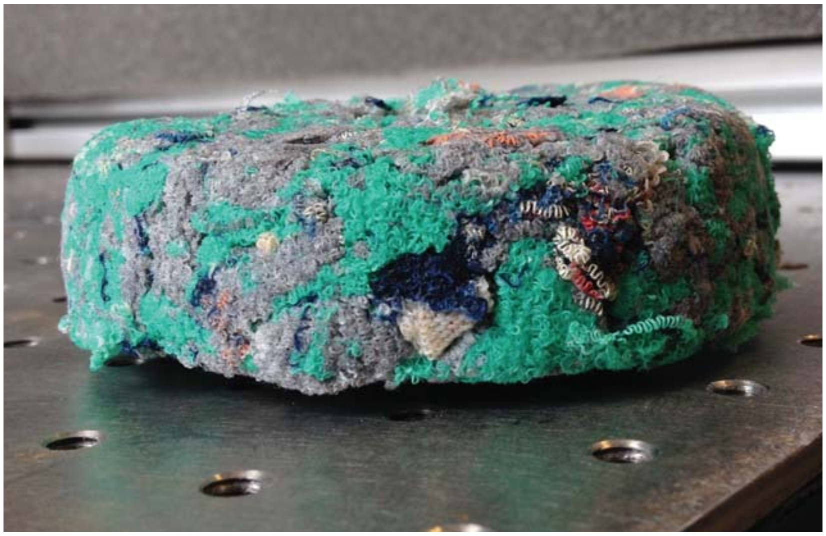
	Diameter		**Thickness**	
Fabric Stiffener	**in**	**cm**	**in**	**cm**
	4.09	10.39	1.25	3.18
	3.99	10.13	1.23	3.12
	4.08	10.36	1.22	3.10
	3.85	9.78	1.27	3.23
Average	4.00	10.17	1.24	3.16
Radius	2.00	5.08		
Silicone	3.15	8.00	1.14	2.90
	3.18	8.08	1.09	2.77
	3.15	8.00	1.16	2.95
	3.81	9.68	1.00	2.54
Average	3.32	8.44	1.10	2.79
Radius	1.66125	4.219575		

Appendix 2 Proof of Contest Submission



Appendix 3: Additional Images of Prototypes

Fabric Stiffener



(a) Side View

(b) Side View 2

(c) Back view

Silicone

(a) Side View

(b) Back View