Table of Contents

Table of Figures

Table of Tables

1. Problem Formation

1.1.Introduction

The purpose of the problem formation section is to provide background on the project, define the objective of the team, and to show how the upcycled benches will affect the world, using a Black Box Model.

1.2.Background

Catherine L. Zane Middle School in Eureka, CA, is the client for the upcycled benches. The school focuses on science, math, engineering, art, and technology and is made up of 600 students, grades six through eight, of varying backgrounds. Our client representative is Trevor Hammons.

1.3.Objective Statement

To create upcycled benches used for educating both students and faculty about the recyclable use of material waste in the community, campus beautification, and for sitting purposes.

1.4.Black Box Model

The Black Box Model shown in Figure 1-1 is meant to show the state of the world before the project is implemented and the state of the world after the project is implemented.

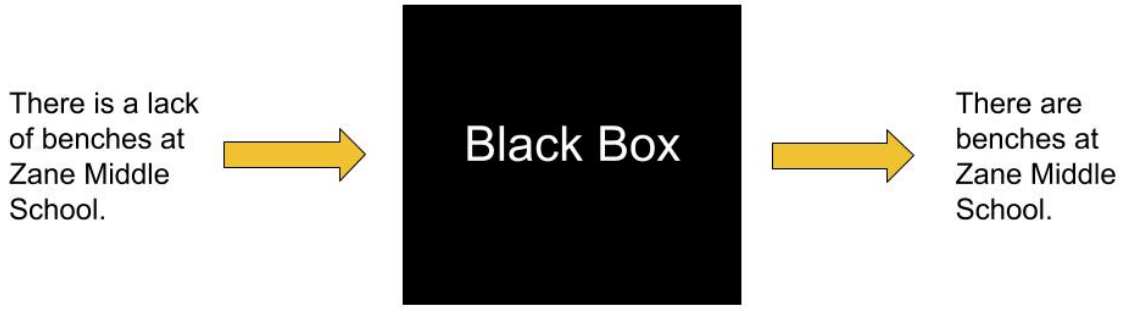


Figure 11: The Black Box Model for Team FMLD's upcycled benches.

2. Problem Analysis and Literature Review

2.1.Problem Analysis

The Problem Analysis section provides an analysis of the preferences of the client. This section covers considerations, specifications, criteria and constraints, production volume, and usage for the upcycled bench project.

2.1.1. Considerations

Considerations are the factors that provide context for the project. Considerations for the Upcycled Benches project are that it will be constructed for children in the 6th-8th grades, the benches may be in different areas on the campus with different forms of weather cover and

different allotments of space. Other considerations include that the average weight of a 7th grader is 90 lbs. so the total capacity of the benches must be at least 200 lbs.

2.1.2. Specifications

Specifications are the minimum requirements the project must meet. They provide parameters for the project. The specifications for the upcycled bench design are, the benches must be located at Catherine L. Zane Middle School in Eureka, the bench must utilize upcycled materials, and the bench must be safe for children.

2.1.3. Criteria and Constraints

Criteria identify the scope of the project and the constraints set limits on that scope. Each of the criteria listed in Table 2-1 are weighted on an analogue scale of importance to better achieve the goals of the project.

Table 21: Criteria and Constraints Defined

Criteria	Constraint	Weight
Cost	Maximum cost of $400 is not to be exceeded ($75 per person and $100 from client).	9
Durability	Must be able to hold at least two average sized middle schoolers and survive weathering outside.	7
Safety	Must not harm the user.	10
Level of upcycle	Must utilize recycled materials in some way.	6

2.1.4. Production Volume

Two benches will be constructed for use at Zane Middle School.

2.1.5. Usage

The benches will be used as a place to sit for students and faculty during the academic school year both during school hours and at after school programs and events. The benches will be used daily.

2.2.Literature Review

The purpose of this literature review is to give insight on materials, essential knowledge, and background information for designing upcycled benches. This section includes client criteria and materials.

2.2.1. Client Interview

The client representative of Catherine L. Zane Middle School was interviewed regarding the criteria of the upcycled bench project. The representative was Trevor Hammons, the school's Counseling Services Director who has been the client representative for other ENGR 215 design projects in the past.

2.2.1.1.Client Design Specifications

The client's specifications for the benches were two to three benches, preferably about 6 feet in length. The length of the benches would be dependent on the permanent location which has not yet been decided. Figure 2-1 shows a possible location where a smaller bench would be employed due to the electrical outlet and water spigot on either side. The client would prefer the benches be made of upcycled material, specifically street signs. If street signs are not feasible, the client would like the benches to incorporate an educational aspect.

Figure 21: Possible location of small bench outside a classroom at Zane Middle School.

2.2.2. **Material Considerations**

This section provides an overview of possible building materials for benches. The section covers wood, street signs, concrete, urbanite, and earthbag building materials.

2.2.2.1.Wood

Wood degradation is usually due to weathering or biological causes (Belie et al. 2000). Pressure treated wood or preservative treated wood usually has added chemicals that act as fungicide, provide UV protection, or make it decay resistant. Wood treatment is usually necessary for outdoor building but treatments such as borate and glycols can be used to provide a protective outer layer to the wood (Canadian Wood Council 2018). Naturally durable woods, such as Western Red Cedar, are recommended to avoid deterioration (Belie et al. 2000). Naturally hardwoods are usually most costly as building materials.

2.2.2.2.Street Signs

Street signs are primarily made of sheet aluminum. For bench building, the sign must be welded and bent. Depending on the size of the sign, a panel bender, press brake, or a folding machine can be used to bend the metal (Heston 2018). Press brakes press down on the metal portion loaded into it and whip the other side of the metal up. Depending on the size of the metal piece, this machine can require multiple operators. Folding machines clamp the metal in place as a beam pushes down on the metal to fold it (Heston 2018). These machines can cost hundreds of dollars. To make the edges of the sign less sharp, the edges can be rolled in so that the sides become rounded. Figure 2-2 shows a bench made from a repurposed street sign with rolled edges made by Dan McCauky. Metal street signs are usually galvanized meaning that the metal is coated in a thin layer of more reactive so that when the sign oxidizes or rusts it "prefers" the more reactive metal. Because the Zinc coating keeps the sign from rusting, weathering is not an issue, but a new coat can be applied to further protect the metal (Natrup 2014).

Figure 22: Upcycled street sign bench by Dan McCauky.

2.2.2.3. Concrete

Concrete as a building material is highly durable. It cannot be easily destroyed due to vandalism and can easily be scrubbed or painted in cases of graffiti. Its durability and levelness can be affected by temperature and moisture changes during its drying process. To prevent this, the cement should be covered during the drying process (Encyclopedia Britanica 2017). Additives can also be used to counteract this, but it is not as necessary on smaller projects such as school benches. Concrete can be poured over other structures such as earthbag construction as a covering to provide more stability and durability (Grenthal, et al 2014). Its relative cost is from $10-$30 per bag at local businesses.

2.2.2.4.Urbanite

Urbanite is broken pieces of used concrete. It can be used in construction in replace of stone. It is usually available for free or at very low costs from demolition sites. Mortar or sand can be used to fill in the spaces between the urbanite and to aid in leveling the different heights of the pieces (Evans et al. 2002). Urbanite can be covered in a layer of concrete for a smooth outward appearance.

2.2.2.5.Earthbag

Earthbag construction uses stacked bags of soil covered in a cement mixture or other frame to build structures. There does not need to be an exact mixture of soil except, there must be adequate moisture and clay content to bind the contents together. Polypropylene bags are recommended for encasing the soil due to their half-life of 500 years and high impact resistance, but sandbags and other recycled materials can be used as well (Dr. Geiger, Zemskova, K. 2016). Barbed wire can be used to further hold the bags in place but is not necessary to overall structure. Earthbag structures have high durability, many earthbag constructions survived the 2015 earthquake in Nepal (Dr. Geiger, Zemskova, K. 2016). The costs are relatively low. Other engineering groups who have used this material in bench building had to just purchase the sandbags and cement for covering, making the cost lower than that of other possible materials like wood (Grenthal, et al 2014).

2.2.3. **Defensive Architecture**

Defensive architecture is a way of designing a public space such that it discourages people from using it any different than what the owner intended its use. Defensive architecture is mostly implemented in urban settings to either keep the homeless from sleeping in public or keep skateboarders from riding concrete benches (The Guardian 2015).

2.2.3.1.Bars

One of the most visually prominent ways to deter from misuse is a handrail that bisects the benches, specifically to keep homeless from sleeping on them in public. Figure 2-3 exemplifies this.

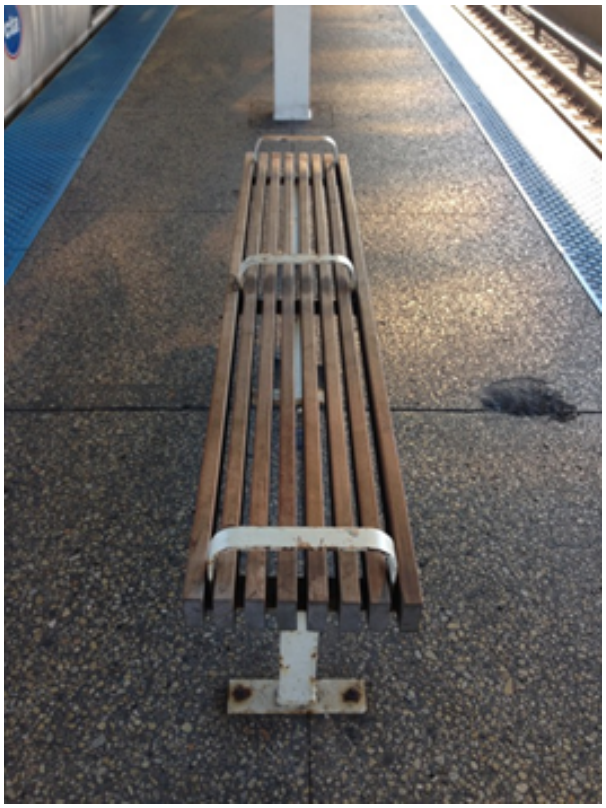


Figure 23: Example of a Defensive Bench

2.2.4. Health Benefits of Children Being Outside

This section goes over the benefits children can get from being outdoors more often. The topics discussed will be Vitamin D and sense of wonder.

2.2.4.1. Vitamin D

Vitamin D can be obtained by getting direct sunlight to bare skin. This vitamin helps ensure the body absorbs and retains calcium and phosphorus, both critical for building bone (Healthy Children 2016). Most children tend to stay inside more so now than ever which has resulted in higher cases of Vitamin D deficiency, the trend of increasing Vitamin D deficiency and rickets is shown in Figure 2-4. This deficiency can lead to a bone-softening disease known as rickets which continues to be reported in the United States mostly in children and adolescents (Healthy Children 2016). Figure 2-5 shows a comparison between healthy bones and bones affected by rickets.

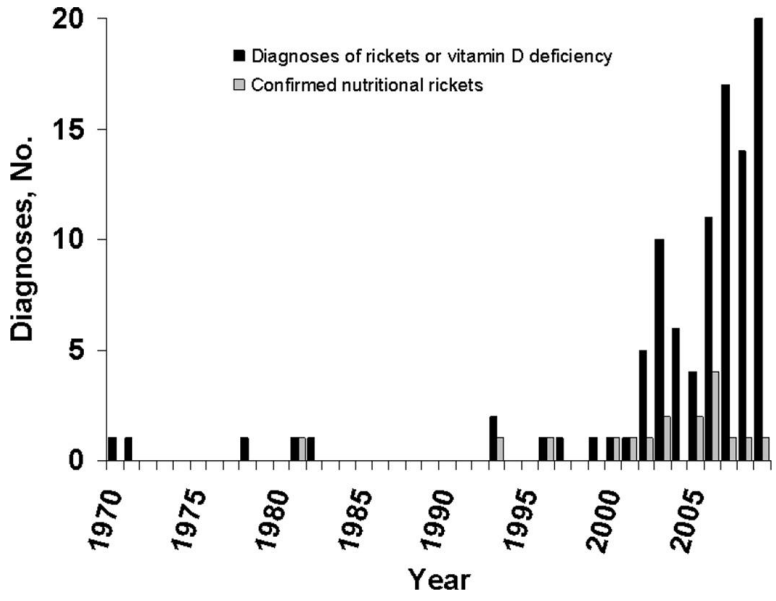


Figure 24: Graph reporting the diagnosis of rickets and confirmed nutritional rickets over a 35-year time period (Thacher et al.2013).

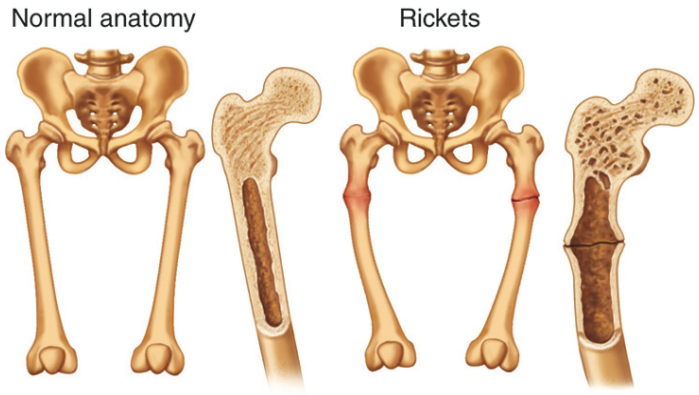


Figure 25: Diagram of healthy bones and bones affected by Rickets (Open Learning Initiative 2015).

2.2.4.2.Sense of Wonder

A kid being outside frequently creates a unique sense of wonder that no other environment can provide (Cohen 2018). Children's being outside also inspires them to ask more questions about the earth and the life that it supports (Cohen 2018).

2.2.5. **Visual Learning**

Visuals are used in teaching because it helps the students obtain information and remember it. The human brain is better at processing images than it is at processing words, as images are interpreted better than text while learning (Thermopylae Sciences 2014). The human brain can

process entire images exposed to the eye in as little as 13 milliseconds (Trafton 2014). Around 40 percent of learners respond better to visual information than text alone. Visuals can decrease the time used to learn a subject and increase retention (Kouyoumdjian 2012).

2.2.5.1.Learning Style

Visual learners understand material better by using their eyesight (Wegman 2014). These types of students create images in their heads to make it easier to recall information (Wegman 2014). Visual aids such as graphs and maps also enhance learning. For example, Figure 2-6 shows a visual aid used to teach children about the digestive system. Demonstrations while learning a new concept or idea also improves comprehension of the subject by allowing students to see what they must do in order to achieve the desired outcome (Wegman 2014).

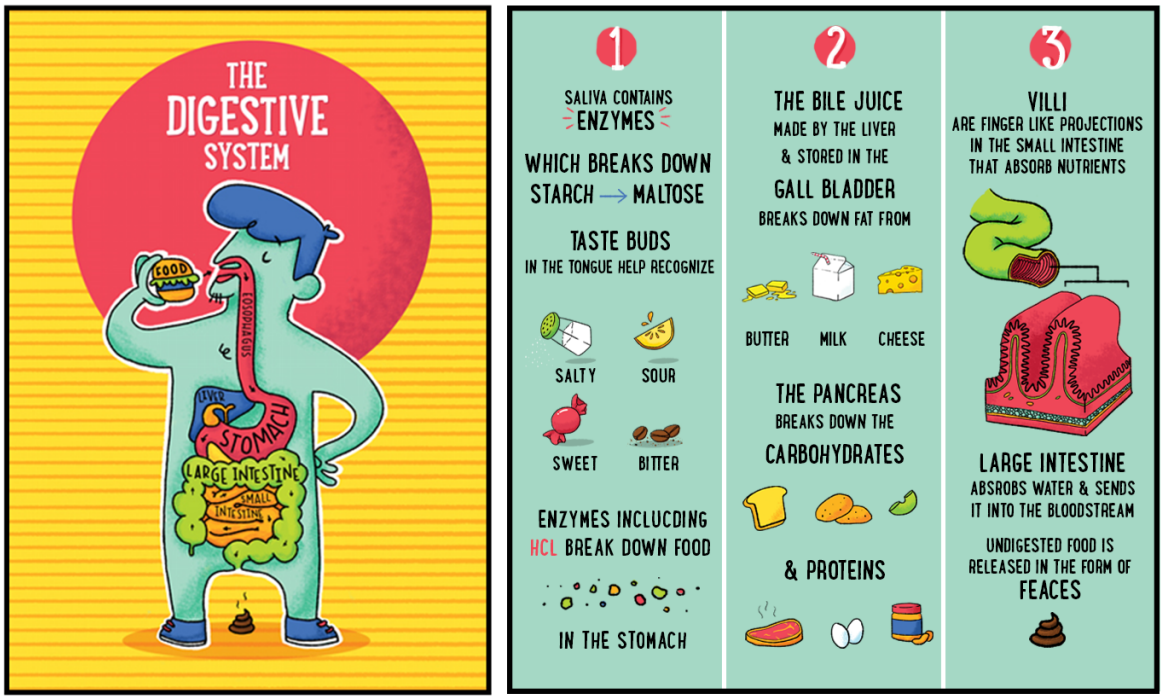


Figure 26: A visual aid for visual learning example (Aswani 2017).

2.2.6. **Aesthetics**

This section provides information about the shape of the bench for it to be aesthetically pleasing and comfortable.

2.2.6.1.Ergonomics

The purpose of this section is to provide ergonomic considerations for the design of the bench.

2.2.6.1.1.Chair

Figure 2-7 shows chair design standards that are set for an adult male who is approximately 5’10” tall (Noe 2015). These standards have been set so that the chair is comfortable and supportive. However, the height of the average 13 year old can range from 4’11" at the 10th percentile to 5' 5 3/4" at the 90th percentile, because of this difference, the dimensions of the chair should be adjusted accordingly (B 2017).

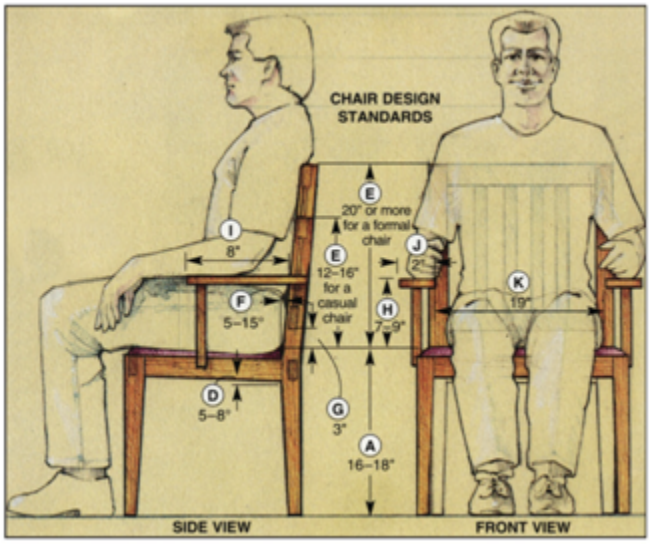


Figure 27: Basic chair design standards (Noe 2015).

2.2.6.1.2.Lounger

The design of the bench should be somewhere between a chair and the lounger pictured below in Figure 2-8. The purpose of the bench is for comfort and relaxation, a break from hard desk chairs, during break times such as lunch and recess. Like the chair, these dimensions are set for a 5’10” adult male and should be adjusted to accommodate the size of a middle school student (Noe 2015). The shape of the bench should be such that it provides comfort and support.

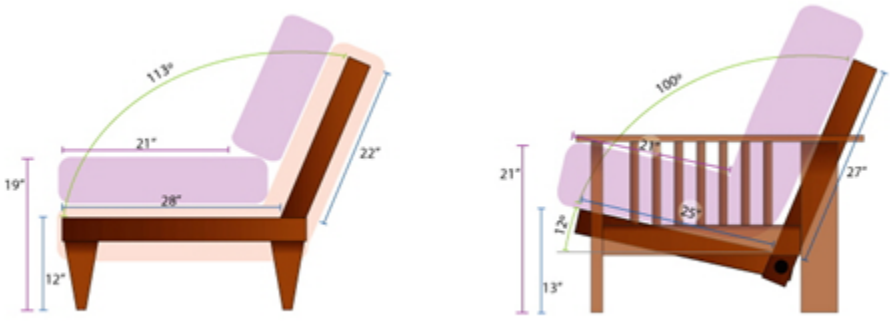


Figure 28: Basic sofa/couch/easy chair design standards (Miller 2005).

2.2.6.2.Landscape Architecture

The bench should be large enough to hold several middle school students and allow them to maintain a personal distance of 0.5 to 1 meter (Loidl 2014). In landscape architecture, public landforms such as benches are typically designed with this in mind. Location is also important. Public benches are often placed in such a way that they are looking out onto a scene, like a beautiful view or a city street.

2.2.7. **Upcycling**

This section gives an overview of materials that could be upcycled and incorporated into the bench. Figure 2-9 shows the municipal solid waste composition that went into landfills in 2010. The following subsections provide information about types of municipal solid waste that can be incorporated into the bench and, therefore, diverted from a landfill.

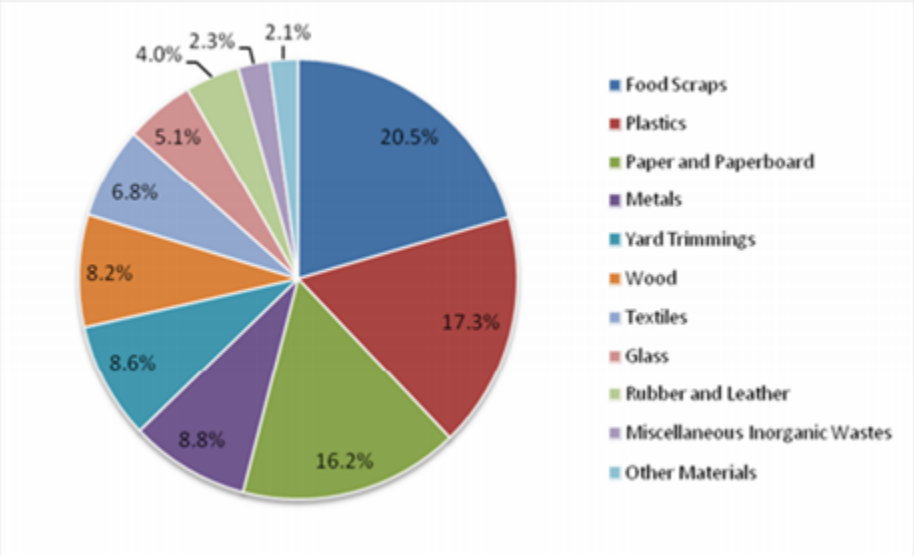


Figure 29: Material Composition of the MSW Stream, 2010 (US EPA 2014).

2.2.7.1.Non-recyclable materials

Thin plastics, Styrofoam, rubber, and PVC are viable options to incorporate into the bench because they are all non-recyclable and would end up in a landfill otherwise. These materials would work the best because they do not decompose quickly. They are also water resistant and easily recognizable.

2.2.7.2.Compact Discs (CDs)

CDs are a potential material to upcycle into the bench because they are another non-recyclable material that typically goes into landfill. Also, that can be easily made into a mosaic, as seen in Figure 2-10 that would add some sparkle to the bench and make it more aesthetically pleasing. CDs would also be easily recognizable in the bench and could create a connection between upcycled materials and objects a middle school student might have used and be familiar with.

Figure 210: Recycled DVD mosaic plate (Upcycle That 2017).

3. Alternative Solutions

3.1.Introduction

Alternative solutions are developed to meet project criteria for the upcycled benches as a result of team collaboration. Brainstorming sessions were utilized to aid in alternate solutions. Ten alternative solutions were developed during both an unstructured and structured brainstorming sessions.

3.2.Brainstorming

Both unstructured and structured brainstorming sessions were held utilizing a whiteboard in a classroom. Unstructured sessions are freer flowing and Structured sessions have a system or restraint to keep on topic. The purpose was to generate ideas and build off of them to see how plausible they might be. Many of the benches' upcycled materials were discussed, such as urbanite, street signs, and wood. Figure 3-1 shows the results of the unstructured brainstorming session and Figure 3-2 shows the outcome of the structured session.

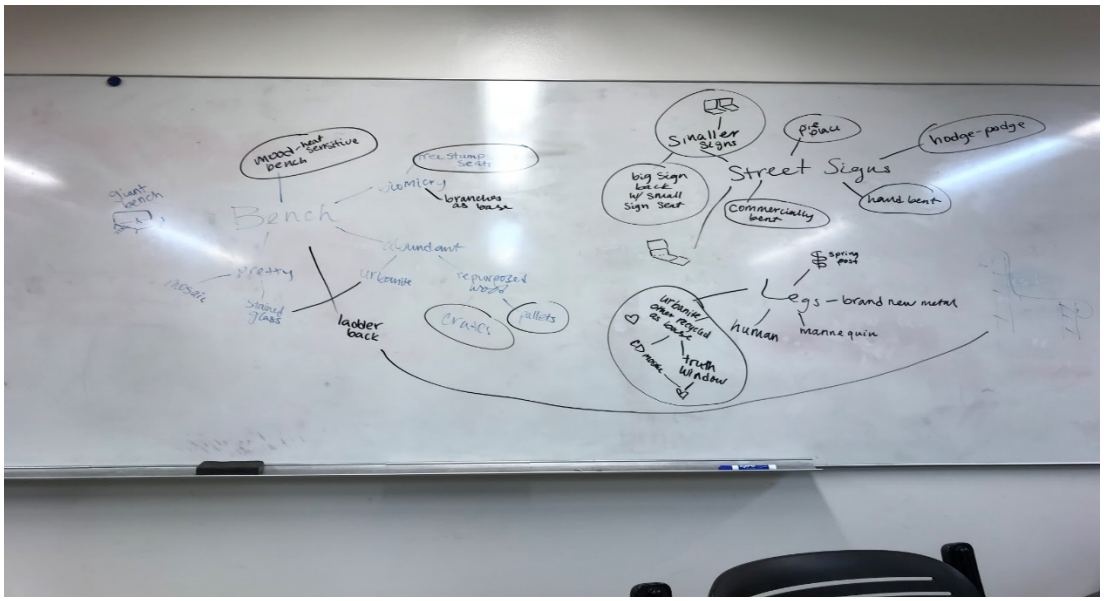


Figure 31: Unstructured brainstorming session (Photo by Andrew Barron)

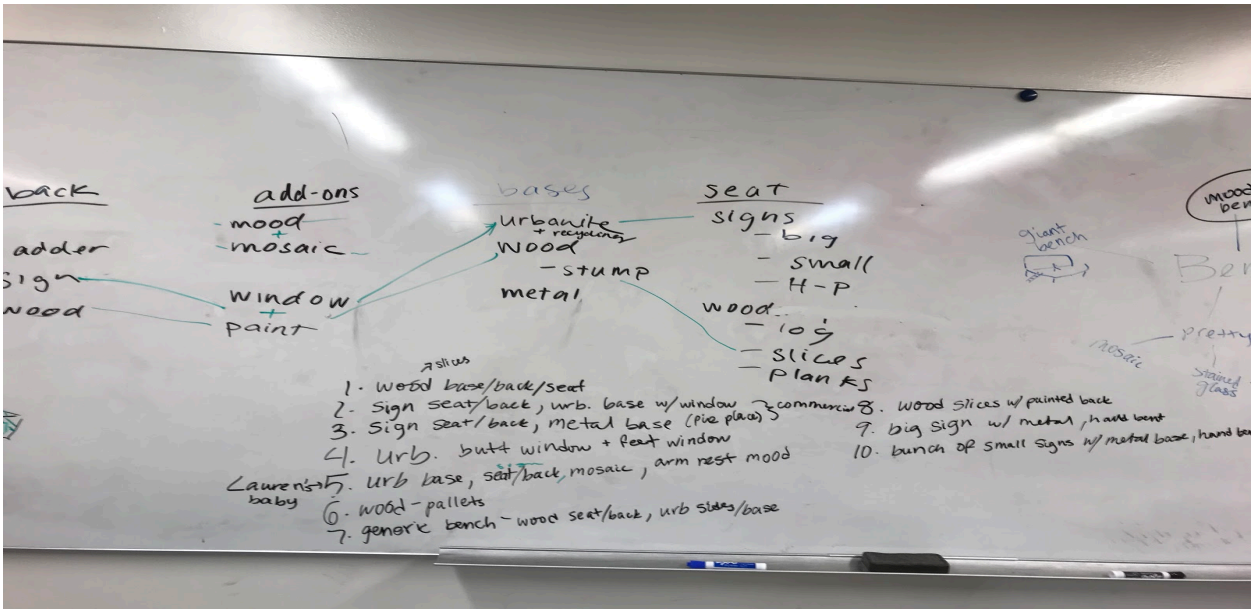


Figure 32: Structured brainstorming session (Photo by Andrew Barron).

3.3.Alternative Solutions

The following is a list of alternative solutions that were developed in a brainstorming session. Each solution is depicted in a sketch/visual.

- Signed, Urbanite
- “Your Butt Here!”
- Urban Development
- Old Reliable

- It's a Sign of the Times
- Ye Olde Hodge-Podge
- Nice and Smooth
- Woody
- Pallet Bench
- Rounds

3.3.1. Alternative Solution: Signed, Urbanite

The Signed, Urbanite solution in Figure 3-3 employs six small upcycled signs. The signs are laid out in such a way that three signs form the seat of the bench and three signs form the back of the bench. The signs are not bent. The base of the bench is made of urbanite covered in a layer of cement for a smooth appearance and for added durability. The smooth cement layer also helps to ensure safety. The signs are affixed to the urbanite/cement base for added aesthetic value and compliance with the client's preferences. On the side of the urbanite base there is a "truth window" in which people can look into to see the hidden use of upcycled materials. The truth window is a plexiglass window affixed on the side of the base. This solution is relatively inexpensive due to the amounts of upcycled materials used.

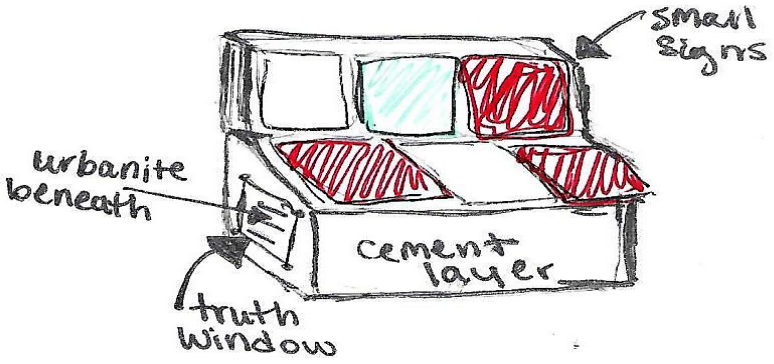


Figure 33: Signed, Urbanite bench (photo by Fiona Roper)

3.3.2. Alternative Solution: "Your Butt Here!"

The "Your Butt Here!" solution in Figure 3-4 involves one large upcycled highway sign. The sign is bent commercially to have a clean crease at close to a 90-degree angle. The bent sign forms both the seat and the backrest of the bench. The top and bottom edges of the sign are commercially rolled to soften the edges, which insures that the user of the bench will not be harmed from the sharp metal edges of the sign while sitting. The base of the bench is made of metal supports. Metal braces are placed under the left and right sides as well as the middle of the sign, which adds support to the bench to prevent collapsing and helps to increase the weight limit of the bench. The metal base is welded together to ensure firm connections. This solution is relatively expensive because the metal and sign are commercially bent and welded.

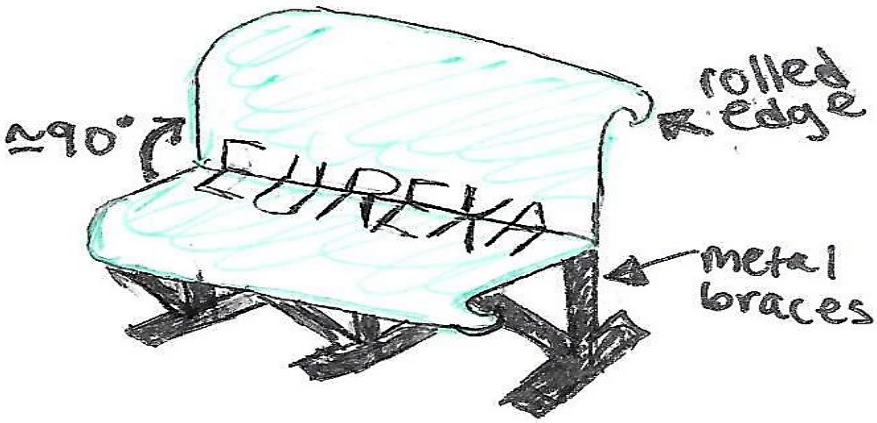


Figure 34: "Your Butt Here!" bench (photo by Fiona Roper)

3.3.3. **Alternative Solution: Urban Development**

The "Urban Development" solution utilizes an urbanite core, truth windows, and a concrete covering as seen in Figure 3-5. The truth windows are meant to emphasize the educational value for the kids as they can see that most materials can be recycled one way or another. The bench is very durable due to being solid urbanite and concrete. This solution is relatively inexpensive due to its use of upcycled urbanite.

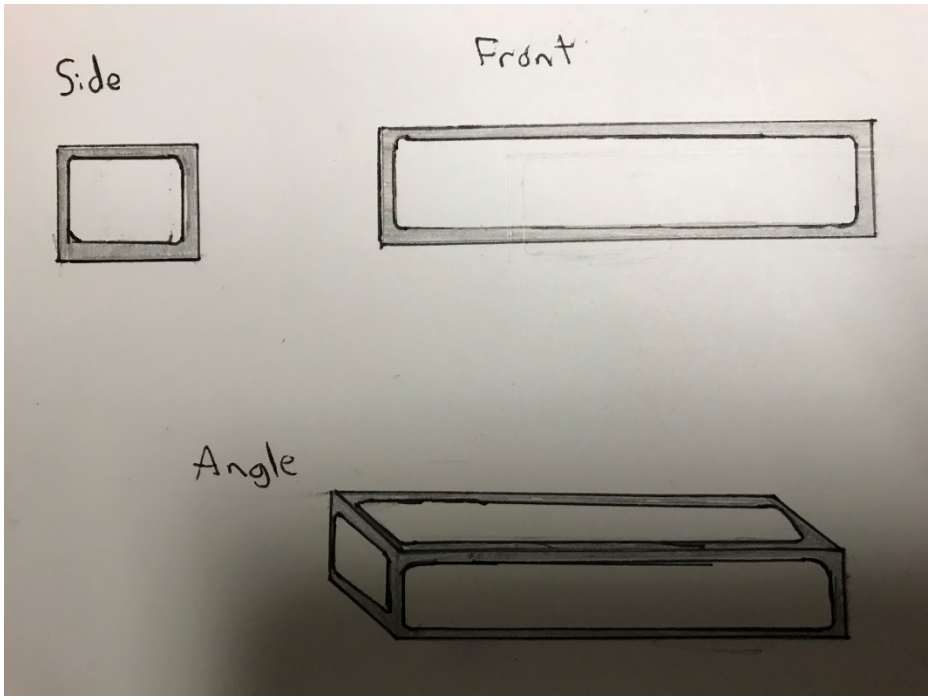


Figure 35: Urban Development bench (photo by Andrew Barron)

3.3.4. **Alternative Solution: Old Reliable**

The “Old Reliable” solution is heavily inspired by benches found in public spaces, but with large, cut urbanite chunks that make up the ends and legs of the bench. The base and seats of the bench are made of donated or reclaimed wood as pictured in Figure 3-6. The bench is fairly expensive due to the pricing of wood. The bench is durable due to its urbanite siding as a support.

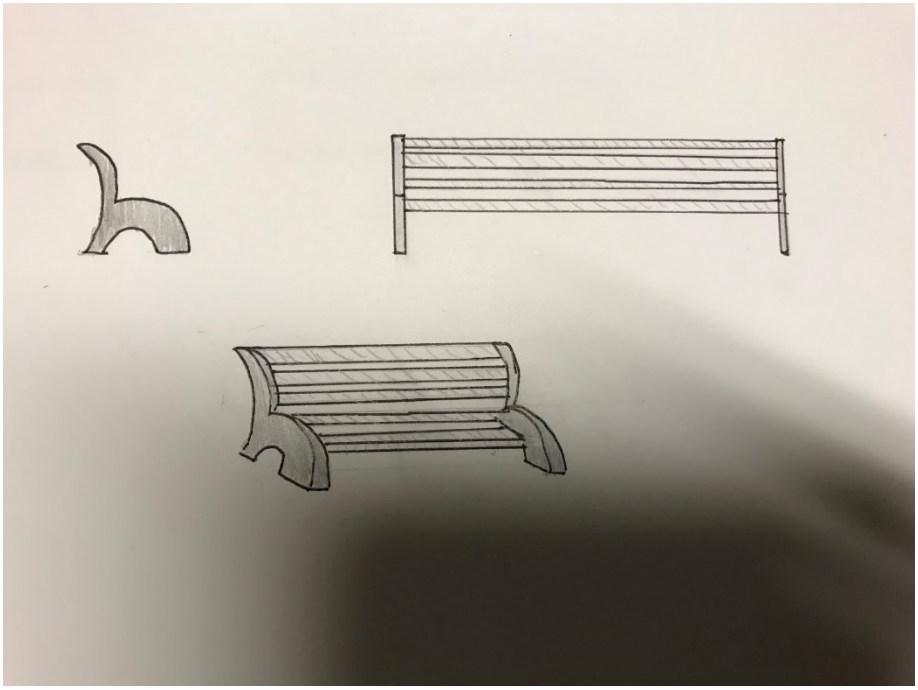


Figure 36: Old Reliable bench (photo by Andrew Barron)

3.3.5. **Alternative Solution: It’s a Sign of the Times**

The “It’s a Sign of the Times” solution in Figure 3-7 consists of an urbanite base and a large, bent freeway sign as the seat and back. The urbanite is covered with a mosaic made of upcycled CDs and DVDs, with a resin layer over the top for safety and protection from wear. The large freeway sign is secured on top of the urbanite base. Heat sensitive paint is painted over the top and down the front of the armrests. This bench is fun and flashy while also putting the upcycled materials on display. The sign is hand bent which lowers the cost, as does the use of upcycled materials. The urbanite base provides for a durable structure.

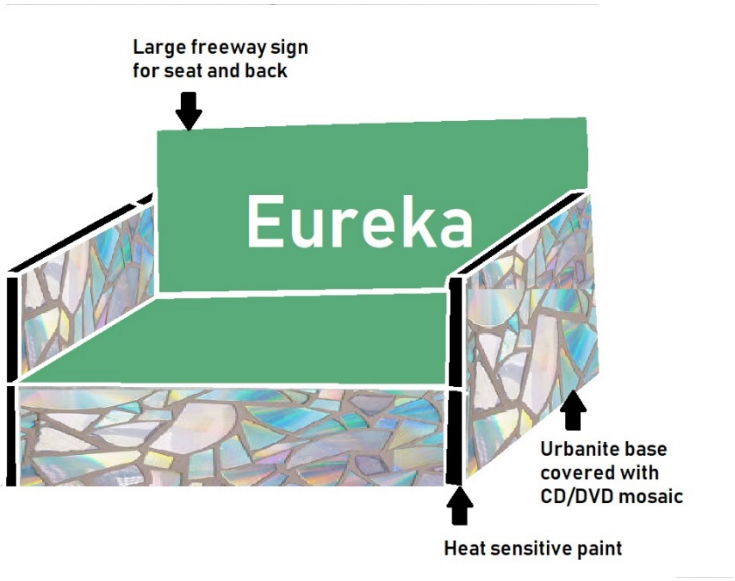


Figure 37: "It's a Sign of the Times" bench (photo by Lauren Yarbrough)

3.3.6. Alternative Solution: Ye Olde Hodge-Podge

The "Ye Olde Hodge-Podge" bench shown in Figure 3-8 consists of an assortment of smaller street signs secured together. The signs sit atop a metal base. This bench can be made using any approved combination of signs. This bench is fairly basic in the sense that it uses very few materials while still showing off that those materials have been upcycled. This bench is also hand bent which brings down its relative cost. It is on the lesser end of durability due to its simple supports.

Figure 38: "Ye Olde Hodge-Podge" bench (photo by Lauren Yarbrough)

3.3.7. **Alternative Solution: Nice and Smooth**

The “Nice and Smooth” bench solution shown in Figure 3-9 is a take on the “Your Butt Here” solution in Figure 3-4. The notable and key difference between these two benches is that the “Nice and Smooth” bench is bent using hand tools, if having the sign commercially bent does not fit within the budget. This bench features a smoother, more gradual curve between the seat and back, as opposed to the clean angle of the “Your Butt Here”, that can only be achieved using large machinery. This bench has all the benefits of the “Your Butt Here” while being a slightly more affordable option. The appearance of this bench is not as professional looking due to the hand bent method of manufacturing.

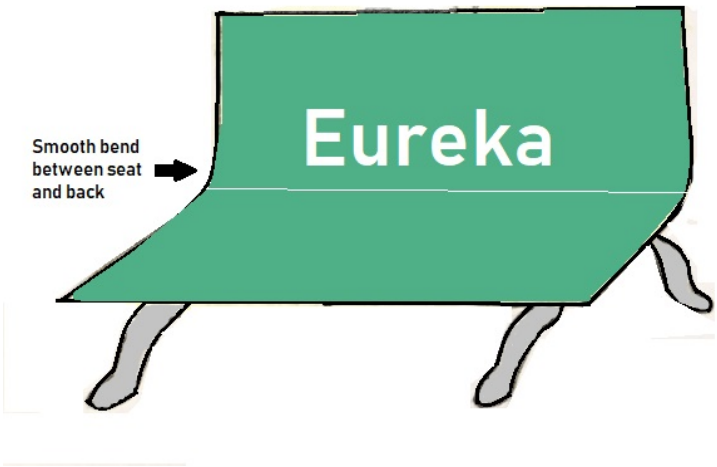


Figure 39: “Nice and Smooth” bench (photo by Lauren Yarbrough)

3.3.8. **Alternative Solution: Woody**

The “Woody” solution in Figure 3-10 entails a large slab of wood, tree slices, and thick tree branches. The large slab of wood serves as the seats for the bench which is supported by thick tree branch legs. The backs of the benches are 3 individual tree slices that are connected to the seats by using smaller thick tree branches. The armrests for the bench are halves of the wood slices which are held up by more tree branches that also connect to the slab of wood. This bench is fairly inexpensive but less durable to the differences in wood pieces used. It has the potential to use a lot of upcycled materials if the right sizes of tree branches are found.

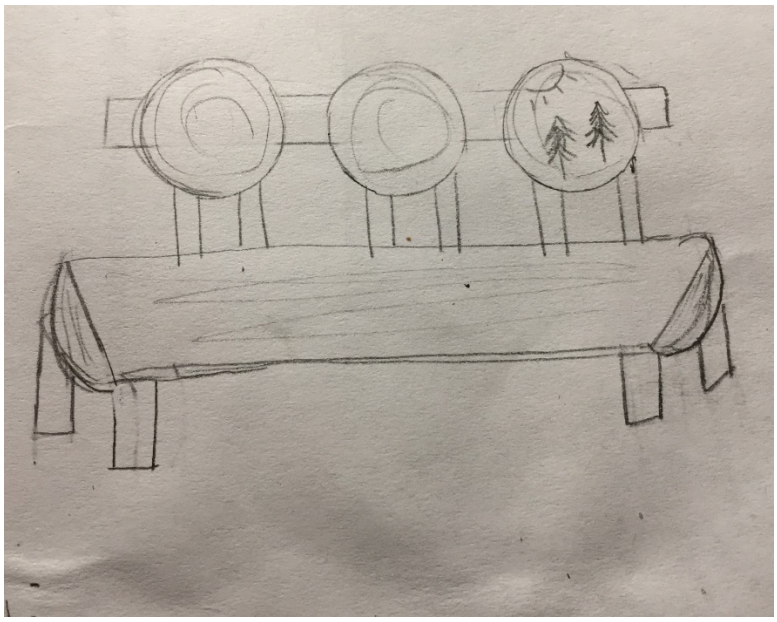


Figure 310: "Woody" bench (Picture by Michelle Campos)

3.3.9. **Alternative Solution: Pallet Bench**

The "Pallet Bench" solution in Figure 3-11 is primarily made of recycled wood pallets. The base of the bench are two pallets screwed together in a rectangular shape. The back of the bench is half of a pallet placed horizontally with two extra boards added to fill in gaps. The back of the bench is inserted to the base by having vertical board extensions that are screwed into place. This solution is very inexpensive due to its use of upcycled pallets. It is fairly durable, though not as durable as solutions using metal or cement bases.

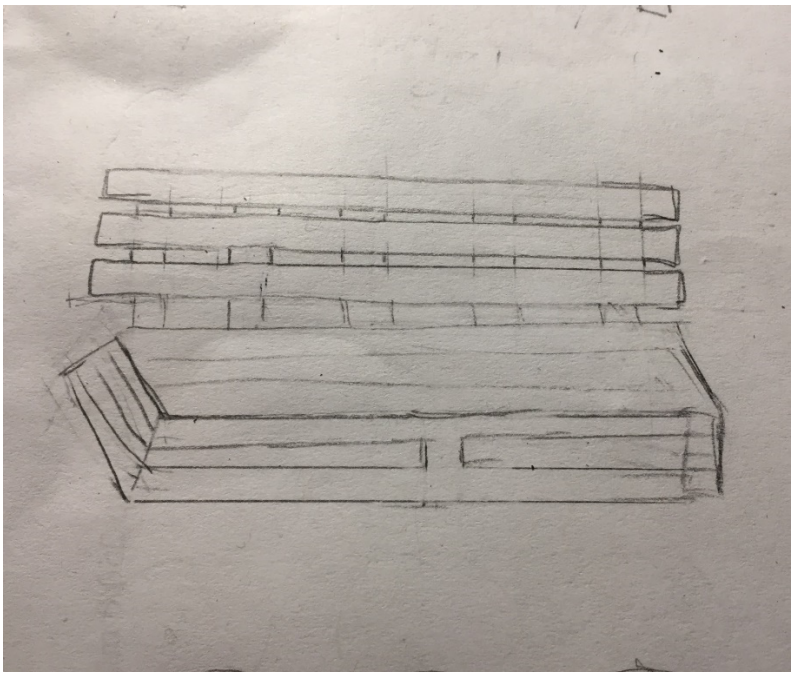


Figure 311: "Pallet Bench" (photo by Michelle Campos)

3.3.10. **Alternative Solution: Rounds**

The "Rounds" solution in Figure 3-12 utilities metal and wood. The base of the bench is a metal table like frame with only two horizontal bars going across. The metal base adds stability and durability. Seats and backs are both tree slices supported by a metal frame of two horizontal bars attached to two vertical bars connecting to the base. The tree rounds bring in an element of nature and aesthetics. The cost of this will be relatively expensive due to the metal needed.

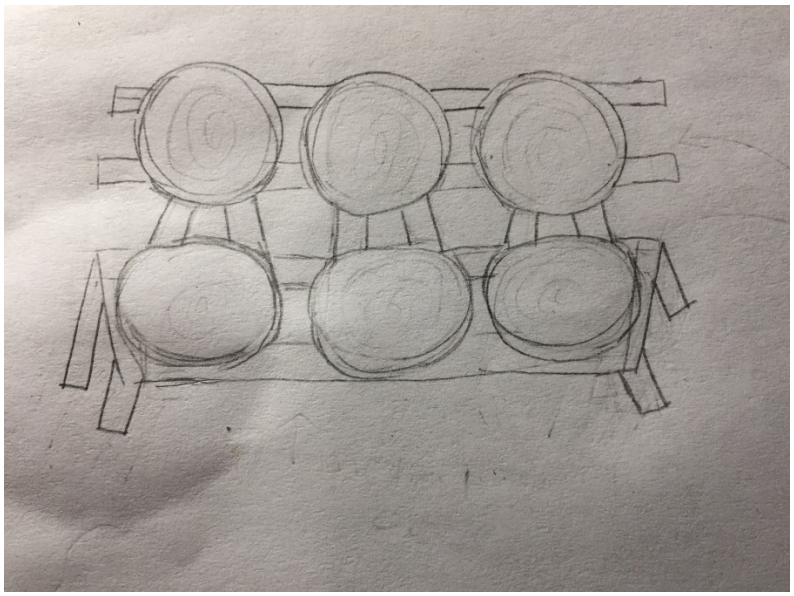


Figure 312: "Rounds" Bench (photo by Michelle Campos)

4. Decision Phase

4.1.Introduction

The purpose of the decision section is to examine the analysis of solutions proposed in Section 3 and the weights of importance proposed in Section 2. The process is completed using a Delphi matrix, which uses the weights discussed in Section 2 to aid the group in the final decision process.

4.2.Criteria

The following criteria are defined in Section 2. These criteria are based on the needs and wants for the project.

Cost: The total money and labor required to construct and maintain the benches being under $400.
Durability: The ability of the benches to withstand the weight and damage of average middle schoolers and weathering on a daily basis.
Safety: The ability of the benches to not cause any safety hazards to the user and follow school safety regulations.
Level of Upcycle: The amount of upcycled material used to create the benches.

4.3.Solutions

The following is a list of the Alternative Solutions presented to the client for consideration, more information on each solution can be found in Section 3.

- Signed, Urbanite
- “Your Butt Here!”
- Urban Development
- Old Reliable
- It’s a Sign of the Times
- Ye Olde Hodge-Podge
- Nice and Smooth
- Woody
- Pallet Bench
- Rounds

4.4.Decision Process

The Delphi Matrix was used to identify the best solution for the final solution. The Delphi Matrix, seen in Table 4-2, works by using the weights of our criterion from Section 2 rated on a scale from 1-10, based on importance, with 10 being the highest as shown in Table 4-1. Then, a score is assigned to each solution from 1-50, with 50 being the highest, of how well a solution meets a criterion. A group consensus was made about the weighting of each criterion for each solution. That consensus is then multiplied by the weights with the final score representing the solution’s ability to meet the criterion set up in Section 2.

Table 41: Criteria and weights.

Criteria	Weight
Cost	9
Durability	7
Safety	10
Level of Upcycle	6

Table 42: The Delphi Matrix

Criteria	Weight	Alternative Solutions (0-50 high)				
		Signed Urbanite	Your Butt Here	Urban Development	Old Reliable	It's a Sign of the Times
Cost	9	35 / 315	30 / 270	25 / 225	20 / 180	30 / 270
Durability	7	45 / 315	40 / 280	45 / 315	32 / 224	40 / 280
Safety	10	30 / 300	30 / 300	40 / 400	35 / 350	40 / 400
Level of Upcycle	6	40 / 240	32 / 192	25 / 150	10 / 60	45 / 270
Criteria	**Weight**	1170	1042	1090	814	1220
		Hodge Podge	Nice and Smooth	Woody	Pallets Bench	Rounds
Cost	9	30 / 270	35 / 315	10 / 90	45 / 405	10 / 90
Durability	7	35 / 245	40 / 280	15 / 105	17 / 119	32 / 224
Safety	10	20 / 200	25 / 250	30 / 300	25 / 250	25 / 250
Level of Upcycle	6	35 / 210	32 / 192	7 / 42	40 / 240	5 / 30
		925	1037	537	1014	594

The client representative was informed of the results of the Delphi Matrix whereupon he expressed a preference for a metal base bench with the use of recycled street signs.

4.5.Final Decision

The final decision chosen for the bench design was an adaptation of the "Ye Olde Hodge-Podge solution. The solution scored high on the Delphi Matrix and the client preferred this design. The adapted "Ye Olde Hodge-Podge" solution will now have a metal frame made from plumbing pipes and connectors. The solution allows for a combination of different sized signs to be used and the frame design allows for the client to bolt the benches into the ground for added durability. The use of plumbing pipes also increases the level of upcycle.

5. Specification

5.1.Introduction

Section 5 of the document is an in-depth analysis of the final solution. This section includes a detailed account for monetary costs, instructions for implementation, and results.

5.2.Solution Description

As detailed in Section 4, the final bench design is an adaptation of "Ye Olde Hodge-Podge". The two benches constructed consist of a metal frame with signs attached for the seat and back.

5.2.1. Metal Frame

The frame of the bench is made up of ¾" galvanized steel pipes screwed and welded together. As shown in Figure 5-1, the frame has four legs standing 16" tall with flanges on the end that can be bolted into the ground in a location of the client's choosing. The frame of each bench has 4 elbow joints, 10 T joints, and 4 flanges. The seat is supported by three pipes parallel to the ground. Due to welding the galvanized pipe, some of the galvanized coating came off. To keep the bench safe from rust, a Cold Galvanizing compound was sprayed on all the joints.

Figure 51: Flange on one of the legs with holes for it to be bolted down.

Figure 52: Elbow joint on back rest.

Figure 53: T joint and welds.

The seat back of the larger bench stands 24” above the seat to support the “School Speed Limit” sign, which is 24” wide and is placed sideways. The total width of the frame is 48” to support the length of the 48” long “School Speed Limit” sign, as well as the four 12” wide “No Parking” signs. The frame of the larger bench is shown in Figure 5-4.

Figure 54: The frame of the larger of the two benches assembled and welded.

The smaller of the two benches is 36” wide to match the width of the two-way arrow sign and the two 18” “Bike Lane” signs. The bottom of the seat back of the smaller bench stands 6” above the seat to support the 12” height of the two “Bike Lane” signs. The seat back on the smaller bench is raised to create a more comfortable back-support height.

5.2.2. **Signs**

Both benches employ upcycled street signs as both the seat and seat back, as can be seen in Figure 5-5. The signs are attached to the frame using multiple methods. The screws, nuts, flat washers, and lock washers used for each attachment method were all stainless steel so that they could survive weathering and the Cold Galvanizing Compound was also sprayed on the backs of the attachments. The signs are standard aluminum street signs collected from local scrap yards.

Figure 55: Completed benches side by side.

As seen in Figure 5-6, the smaller bench has a two-way arrow sign as the seat with two “Bike Lane” signs as the back. The bottom arrow sign is attached to the frame using 5 pipe straps (3 along the back seat bar and 2 on the middle seat bar) to create 2 points of contact for added durability. The front edge of the arrow sign is held in place by 3 screws that go through the pipe. This attachment method was used so that the arrow sign could be recessed to where the front seat bar is slightly exposed to create a smoother edge for the user to hang their legs over. The underside of the smaller bench is shown in Figure 5-7. The “Bike Lane” signs are attached to the back supports by a total of 8 screws through the pipe (4 for each sign). Figure 5-8 shows the through screws circled in red.

Figure 56: Smaller of the 2 benches.

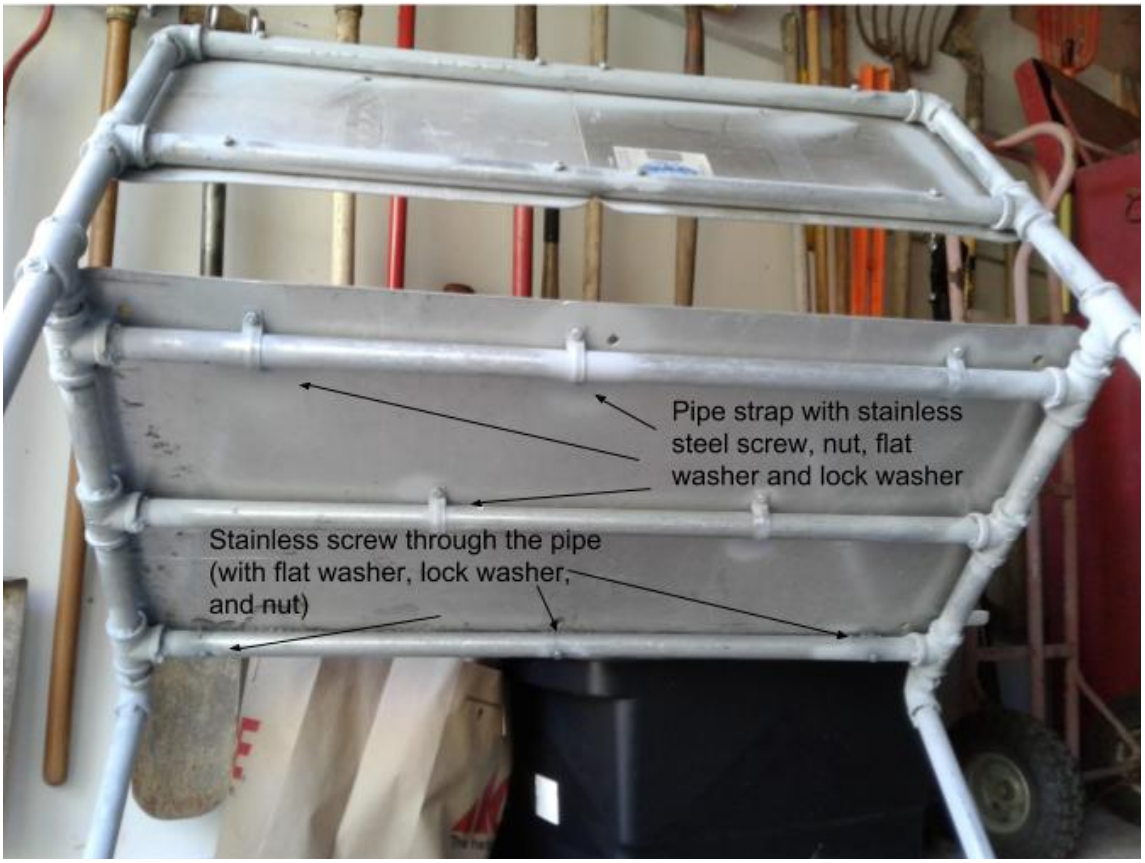


Figure 57: Underside of smaller bench showing attachment methods.

Figure 58: Back of smaller bench with through screws circled in red.

The larger bench, shown in Figure 5-9, has a sideways “School Speed Limit” sign as the back and four “No Parking” signs as the seat. The bottom 4 “No Parking” signs are attached with 4 pipe straps each (2 along the back seat bar and 2 on the middle seat bar) to create 2 points of contact and to prevent the signs from moving. The front end of each “No Parking” sign is attached to the front seat bar using 2 through screws. Like the smaller bench, this is done to create a smoother edge for the user. The various attachment methods for the bottom of the larger bench is shown in Figure 5-10. The “School Speed Limit” sign is attached by 10 through screws (4 on top, 4 on bottom, and 1 on either side). Figure 5-11 shows the through screws circled in red.

Figure 59: Larger of the 2 benches.

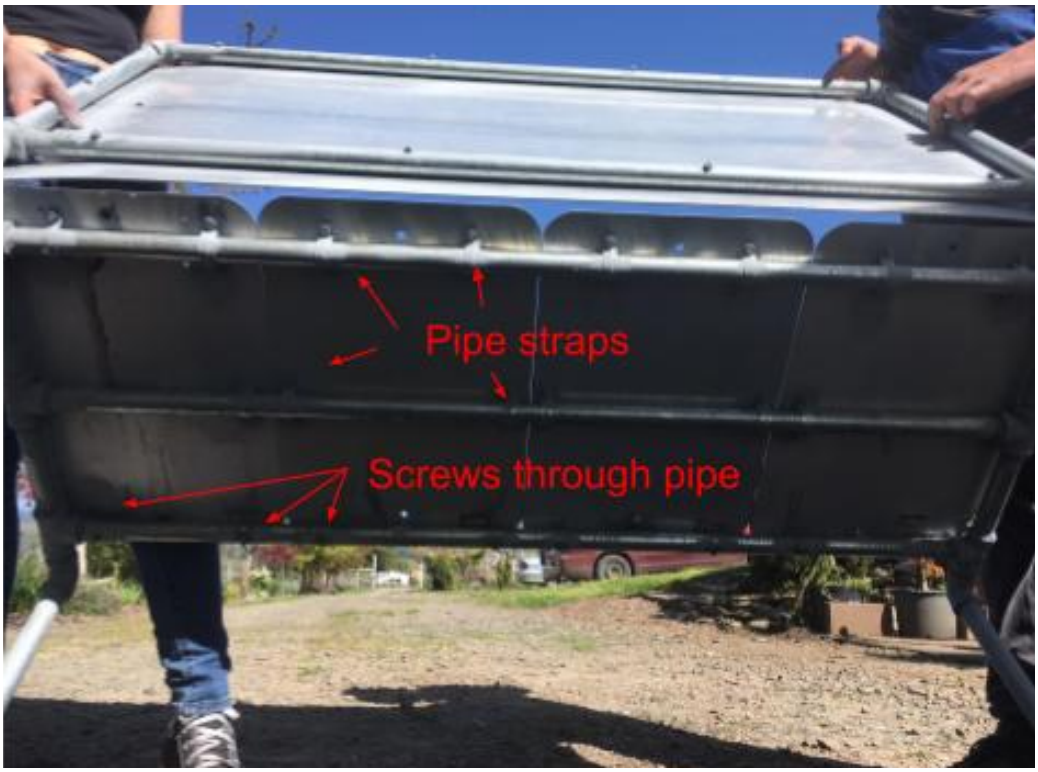


Figure 510: Underside of larger bench.

Figure 511: Back of larger bench with through screws circled.

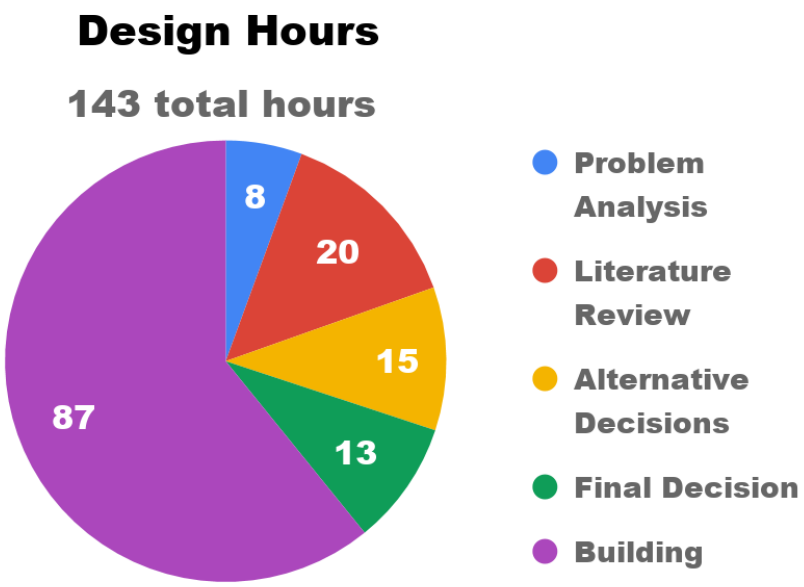
5.3.Cost Analysis

This section provides an analysis of the cost of design, implementation, and further maintenance for the upcycled benches. These costs are expressed in time and money and are represented in the forms of tables and graphs.

5.3.1. Design Costs

Table 5-1 is a pie chart of the total hours spent on the conceptualization of the upcycled benches. A total of 8 hours were spent on the problem formulation and analysis section, 20 hours were spent on the literature review section, 15 hours were spent on the alternative solutions section, 13 hours were spent on the final decision process, and 87 hours were spent on building and specification for a total of 143 hours.

Table 51: Design hours



5.3.2. Implementation Cost

The total retail cost to construct the upcycled benches is $546.56, and the material cost break down is summarized in Table 5-2. Team FMLD received cash donations from Forest Lakes Nursery to cover the costs that went above budget.

Table 52: Itemized cost of materials.

Itemized Cost of Materials

Material	Quantity	Cost	Retail Cost	Team FMLD Cost
Custom cuts 3/4" galvanized	22	$166.25	$166.25	$166.25
3/4" x 1 1/2" galvanized nipple	10	$1.39	$13.90	$13.90
3/4" x 6" galvanized nipple	10	$2.79	$27.90	$27.90
3/4" Ts	20	$3.89	$77.80	$77.80
3/4" 90s	8	$2.29	$18.32	$18.32
3/4" Flanges	8	$6.99	$55.92	$55.92
Street Signs	8	$38.75	$38.75	$38.75
Cold Galvanizing Spray	1	$8.47	$8.47	0
Pipe strap packs of 10	3	$1.49	$4.47	0
Drill bit	2	$4.99	$9.98	0
Various screws	60	varied	$54.94	0
Various nuts	65	varied	$27.64	0
Various washers	130	varied	$7.02	0
			Retail Total	$546.56
			Team FMLD total	$398.84

5.3.3. Maintenance Costs

The final design requires minimal maintenance. Cold galvanizing compound spray will need to be applied to the welded joints every 2 years to prevent rusting. A summary of the cost is displayed in Table 5-3.

Table 53: Itemized and temporal list of estimated upkeep maintenance costs.

Item	Expected Rate of Replacement	Cost
Cold Galvanizing Compound Spray	Every 2 years	$8.47

5.3.4. Implementation Instructions

The upcycled benches are lightweight and sturdy and can be transported as complete pieces. The flanges at the base of each leg will allow for the benches to be bolted down or screwed in place at the client's discretion. The client will need to purchase concrete lag bolts to bolt the flanges down.

5.3.5. Results and Performance

The final results are functional designs that implement industrial and upcycled elements in a way that is comfortable and aesthetically pleasing. The upcycled aesthetics of the bench are used to teach how to reimagine ordinary objects into functional items. The models are meant to be very durable and to withstand weathering and destructive forces of middle schoolers.

6. Appendices

6.1. A. References

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6.2. B. AutoCAD of bench frame