TEAM HANI

The Upcycled Bench Project

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Contents

1 Problem Formulation

1.1 Introduction

The purpose of this section is to provide the background of Team HANI's project as well as an objective statement and a blackbox diagram which addresses the issue of the lack of outdoor seating for students at Zane Middle School in Eureka, California.

1.2 Background

Team HANI is composed of the members: Hayden Miller, India Eichelbaugh-Goss, Andie Kolasinski, and Nicholas Kenne. HANI's members are students in the Engineering 215 Introduction to Design course, instructed by Lonny Grafman during the Spring semester of the 2019-2020 academic year.

HANI's seating project is intended to help solve the problem of insufficient seating arrangements for the students of Zane Middle School in Eureka. The need for this project was revealed by the client, Trevor Hammons. The goal of his proposed project is to add a safe and visually-appealing outdoor seating solution to the front of Zane Middle School. Trevor disclosed that a previous group of Engineering 215 students had designed upcycled seating implements, but those benches are in use inside the office by the staff of the middle school rather than the students. This project will serve to provide outdoor seating where it is lacking and most needed: in front of the school where students wait each day to be picked up by their parents.

1.3 Objective Statement

The objective of this project is to provide outdoor seating to the students of Zane Middle School in a way that promotes sustainability by repurposing used materials while also being aesthetically pleasing. The final design will serve to model the use of appropriate technology outside of the classroom for the students of Zane Middle School. The black box model (Figure 1-1, below) is intended to illustrate the client's problem and what the final solution will provide.

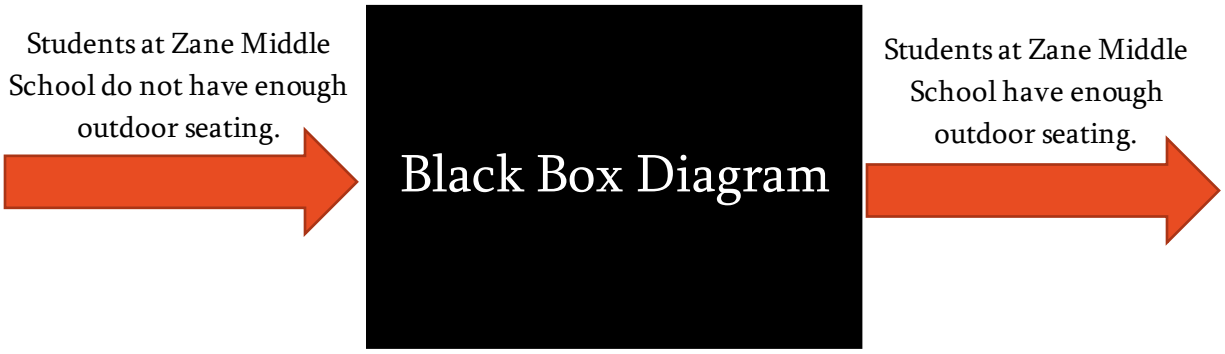

Figure 1-1 Black box diagram for the Upcycled Bench Project. By India Eichelbaugh-Goss.

2 Problem Analysis and Literature Review

2.1 Introduction

This section analyzes the problem that must be addressed and for which a design must be implemented. It also provides literature-based research that will help to address various topics that relate to the problem that must be accounted for during the design process.

2.2 Problem Analysis

The problem analysis provides a detailed summary of various considerations taken into account regarding the design process for the upcycled bench project for Zane Middle School. This section details quantitative and qualitative specifications and considerations, the criteria and constraints, as well as the expectations regarding the production volume.

2.2.1 Specifications

The design for the upcycled bench must meet a few specifications in order to be successfully and effectively implemented at Zane Middle School. These specifications are detailed in the following list.

- The bench must meet or exceed the safety standards for seating of Zane Middle School's district. This means that the bench must be able to be secured (by drilling into existing concrete) to the ground in order to prevent the bench from tipping over and becoming displaced.
- Upcycled materials must be used in the final construction of the bench in order to promote sustainability.
- The bench must be located on campus so that it is visible to both students and parents upon arrival at Zane Middle School.

2.2.2 Considerations

A few considerations must be taken into account during the design process for the upcycled bench for Zane Middle School. These considerations were developed through an interview with the client as well as team-wide brainstorming and research.

The client would like the bench to provide Zane Middle School with "color and variety", preferably near the Rectangle of Doom where students congregate to be picked up after school (Hammons, 2020). Local materials would be preferred for construction and the materials used for the bench should be durable enough to hold up against the weather with minimal maintenance. According to Humboldt County's website, coastal Humboldt County experiences between 40 and 100 inches of rainfall year-round which typically tends to cease between the months of June and August, when Zane Middle School will be out of session for the summer. The temperatures are moderate: the range is typically between about 30 and 80 degrees.

The bench would be placed in a safe location where kids could be supervised and be out of the way of any vehicles and equipment that could be deemed dangerous. The bench should remain functional, year-round, for many years.

2.2.3 Criteria and Constraints

Criteria is a principle or standard by which something may be judged or decided, while constraints set a parameter which the criteria must meet in order to satisfy the goal set in place by the client. Table 2-1 shows the criteria and constraints that are set for this project which will satisfy the client's needs.

Table 2-1 Criteria, constraints, and their quantified importance.

Criteria	Constraints	Weight (scale of 1-10)
Safety	Meets or exceeds school district standards	9
Aesthetically Pleasing	> Onsite Benches	8
Upcycled	> 50%	7
Durability	Equal to onsite benches	7
Cost	< $400	6
Comfort	> Onsite benches	6

2.2.4 Usage

The upcycled bench is meant to be a year-round bench that is durable enough to sit out in the earth's elements. Students and faculty should be able to use this bench as they please. This bench is meant to help ensure the safety of the students while they hang out near the traffic-heavy pickup area in front of the school by providing an area to sit rather than run around and potentially be put in danger by moving cars. As there are school sessions and events held at Zane Middle School year-round, these benches may be utilized at any given time.

2.2.5 Production Volume

The client would like at least one bench to be constructed for and installed at Zane Middle School

2.3 Literature Review

The Literature Review section provides basic information about various topics that might affect the final design of the Upcycled Bench Project. This information was gathered from existing literature.

2.3.1 Client Information

This section provides an account of the interview and meeting with the client contact Trevor Hammons, the Counseling Services Director. It discusses specifications and criteria that the client had in mind at the very start of this project before any further research was done.

2.3.1.1 History of upcycled benches at Zane Middle School

Two previous Engineering 215 teams have attempted to build upcycled benches for Zane Middle Schools' students to use outside. The first upcycled benches were implemented in 2018 by Team FMLD and are still in use at Zane Middle School, but they are in the office and are mostly used by staff (Hammons 2020). The second time that an upcycled bench was made for the students was in 2019. It was intended to provide students with an aesthetically-pleasing place to sit while they waited to be picked up by their parents after school, but it has since been removed as it did not enhance the visual appeal of the campus (Hammons 2020).

2.3.1.2 Design Specifications

The bench design must incorporate upcycling. The design must have "color and variety" and make the pickup area more welcoming and visually appealing for when children are waiting for their parents after school.

2.3.1.3 Design Criteria

The client wants a safe, sturdy, and aesthetically-pleasing set of benches near the "Rectangle of Doom" where the students are picked up after school. The benches should dissuade the students from running through the rectangle while providing them with a comfortable place to wait for their parents. The benches must also be able to be secured to the ground to ensure safety. The client would be pleased if local "Eureka" signs could be used in the design.

2.3.2 Upcycling of Materials

This section provides a description and explanation of the method and goal of upcycling materials.

2.3.2.1 Background and description of upcycling

The general process of upcycling includes taking something that has been used and no longer serves its original intended purpose and improving it to serve a new purpose in a creative way. The goal of upcycling is to reduce the amount of waste created or the amount of energy it might take to recycle materials rather than to repurpose them, and to contribute to a sustainable and "delightfully diverse, safe, healthy, and just world with clean air, water, soil, and power" (McDonough and Braungart 2013). Upcycling is based on the Hannover Principles written for the 2000 World's Fair (Table 2-2, below).

Table 2-2 Hannover Principles, 1992. The foundation of upcycling. (McDonough and Braungart 2013)

1. Insist on rights of humanity and nature to co-exist
2. Recognize interdependence.
3. Respect relationships between spirit and matter.
4. Accept responsibility for the consequences of design.
5. Create safe objects of long-term value.
6. Eliminate the concept of waste.
7. Rely on natural energy flows.
8. Understand the limitations of design.
9. Seek constant improvement by the sharing of knowledge.

2.3.2.2 Advantages of upcycling

There are environmental, educational, financial, and economic benefits of upcycling. For example, reusing materials prevents them from becoming waste and causing greenhouse gas emissions from inside of landfills or incinerators. Less energy is required for upcycling as compared with recycling processes; recycling also degrades the value of the material, whereas upcycling upgrades it. Educational advantages of upcycling include the development of creative skills needed for the construction of new products out of old ones, and basic construction knowledge can be gained as well. Also, since the concept of upcycling is so closely linked with sustainability and nature, upcycling is a good way to bring awareness to how regular people can make a difference and become more environmentally-conscious. It can be much cheaper to upcycle as well, especially if one can find old products or materials that would otherwise become solid waste. This saves money for the people working on a project when new materials do not need to be purchased, and it also saves the government money by reducing transportation and environmental landfill costs, along with the cost of recycling processes (Sung, et. al 2019).

2.3.2.3 Disadvantages of upcycling

Upcycling can also have disadvantages. For one, retailers and manufacturers could lose business if consumers stop purchasing new materials. This would also affect the job market in these areas. Also, upcycling is easy for the average person to do, so occasionally there could be health hazards related to the materials one is upcycling that they are unaware of. An example of this was provided in an anecdote by Trevor Hammons including the welding of galvanized steel for upcycled benches in 2018, the process of which releases a poisonous gas (2020).

2.3.3 Alternative Types of Benches

This section investigates various types and styles of benches currently used in schools and other public areas, and the factors that must be considered for each.

2.3.3.1 Eco-friendly benches

Upcycled benches are already in use at Zane Middle School, although they are inside. They were built in 2018 and are still in use by faculty members there (Hammons 2020). Materials used for construction of these benches include galvanized plumbing pipe and street signs (Barron, et. al), and these benches were significantly less expensive than traditional or recycled benches that can be bought from school supply catalogs. Other eco-friendly benches can be found for sale by retailers, such as benches made out of compacted recycled plastic.

2.3.3.2 Backrests

Backrests can be an important addition to public benches in schools. Children who are running around might use a bench backrest to hold their coat or backpack, or they might want a comfortable place to sit down and read. A variety of comfort-levels can be attained with different styles of backrests. For example, backrests can be anteriorly-curved or vertical, or have no backrest at all (Lusk and Dirksen 1997). Benches without backrests are good for environments where people are meant to sit for only a short period of time because they are less comfortable than benches that provide back support. In schools, children may wait seated on a backless bench for a short period of time for the school bus or for their parents to pick them up.

2.3.3.3 Wall-top benches

Benches that are built without legs attached may also be installed atop short walls (such as one that would be found around a garden area) to form a seating wall. These wall-top benches consist of a slightly-elevated seat which rests upon the top of the wall and may also have a backrest component. The main difference between a wall-top bench and a traditional bench is the absence of legs. Rather than the support for the bench coming from the attached legs, the bench would be supported by the wall on which it sat.

2.3.4 Ergonomics

This section provides an overview of the ergonomics related to seating.

2.3.4.1 Posture

Posture can be defined simply as the position in which an individual carries their body. Ideal posture is a position where the body is aligned in such a way that the forces due to gravity produce minimal stress on the joints and structures of the body (Danis 1998). Proper posture while seated should imitate the ideal standing posture with the goal being to reduce the risk of musculoskeletal disorders and pathology (American Posture Institute).

2.3.4.2 Comfort

A stable sitting posture is important for seat comfort (Kohara 1972). However, it has been difficult for researchers to define comfort, with respect to sitting (Zacharkow 1988). Shackel et al. provided four criteria of consideration when designing a seat: anatomical and physiological factors, observations of body position and movement, observation of task performance, and subjective methods (1969).

2.3.5 Materials

This section investigates various materials that can be used to construct upcycled benches. It mostly includes upcycled materials in order to fit the client's design criteria.

2.3.5.1 Street Signs

Street signs were used by 'Team FMLD', an Engineering 215 group from 2018, to successfully design benches for Zane Middle School (Barron 2018). Due to their success, the client has requested the use of street signs again. They can be found for free in maintenance sheds or 'free piles' around Arcata, donated by the city or Caltrans, or purchased for a low cost at scrap and junkyards. Street signs do not need any further weatherproofing before being turned into an outdoor bench as they're already coated with either engineering grade, 3M High Intensity Prismatic, or 3M Diamond Grade reflective sheeting. These coatings allow signs to withstand weather for 7, 10, and 12 years respectively. (Dornbos Sign and Safety, 2020). After personally testing out the street sign benches made by Team FMLD, the flexible metal of street signs provides firmness and give, making them a comfortable option.

2.3.5.2 Wood

Benches are often seen made from wood. Teak, cedar, and pine are good options for benches, while requiring little to no upkeep. Cedar and pine age nicely on their own, while teak requires an annual oil application to maintain the color. They are listed in order from most to least expensive. Natural or repurposed wood can withstand weather, but only after a coating, paint, or stain has been applied (Feist, 1989). A 2x4 can support around 1,000 pounds vertically, making it a stronger material. A 2x4 of plywood can be found for $23 at a hardware store, for a low cost at junkyards, or donated by lumber mills.

2.3.5.3 Snow Gear

Snowboards and skis utilized as the seat of a bench are potential options as they possess the strength of wood and the same attractive waterproof element of street signs. Snowboards are made with a wood core sandwiched between two pieces of fiberglass with metal edges along the whole rim and a P-tex base. Fiberglass is light but durable and allows for some bend. Metal provides a sturdy but not sharp edge. The P-tex base is a scratch resistant plastic (Mindy 2020). All of these elements are suitable for a long-lasting durable bench. Brand new snowboards can be found for as cheap as $100 and used snowboards that could be upcycled can be found for an even lower budget.

2.3.5.4 Tires

Tires can be used as a simplistic seating arrangement. They can be placed on the ground and are immediately ready to be sat in. Larger tires can be suspended from tree branches or sturdy beams to make a swinging seat that can fit up to three people, depending on the size. They can also be stacked in order to achieve a taller seat, or implemented as backrests on benches with seats made from other material. Tires are not the most visually appealing option for seating, but they provide a comfortable place to sit with a low budget. They are easy to obtain from a junkyard or mechanic shop.

2.3.5.5 Plastic Bottles

Plastic bottles can be used in place of concrete. The plastic can be broken down into PET fiber and can then be used to reinforce concrete, decreasing the total mass of concrete needed while finding a use for seemingly useless bottles. This method was successfully used to pave a road in Japan (Buin 2018). This same method would be useful to make an upcycled concrete-plastic bottle bench.

2.3.6 Skills

This section describes skills that may be needed in order to complete the Upcycled Bench project.

2.3.6.1 Arc-welding

Arc welding uses an electrical arc (sometimes called the welding rod) to melt the work materials as well as filler material for welding joints. Arc welding involves attaching a grounding wire to the welding material or other metal surface. Another wire known as an electrode lead is placed on the material to be welded. Once that lead is pulled away from the material, an electric arc is generated. The arc then melts the work pieces along with the filler material that helps to join the pieces. Feeding the filler into the welding joint takes steady hands and an eye for detail. As the rod melts, the welder must continuously feed the filler into the joint using small, steady, back-and-forth motions. These motions are what gives welds their distinctive appearance. Going too fast or slow, or holding the arc too close or far away from the material can create poor welds (Nguyen 2017).

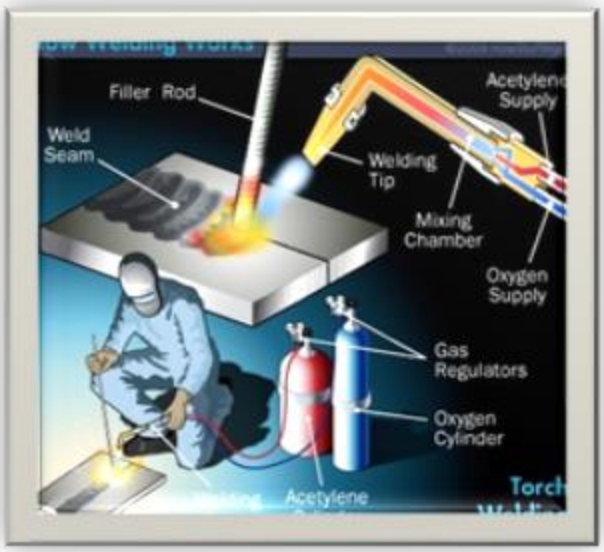

Figure 2-1 A diagram explaining the process of welding.

2.3.6.2 Knowledge of Statics

Statics is the branch of mechanics concerned with bodies at rest and forces in equilibrium. Maximum bending stress allows you to calculate how much loading your bench can take without breaking. Between the gravitational force and the force acting against gravity, the stand-still bench will be in equilibrium. By determining the length and width of the material, it is possible to calculate the maximum weight this rigid body can hold (Meriam 1959).

2.3.6.3 Teamwork

Teamwork skills are the qualities and abilities that enable people to work well with others during conversations, projects, meetings or other collaborations. The ability to communicate in a clear, efficient way is crucial to good teamwork skills. Within the dynamic of teamwork, it is important that every party involved both understands the work he/she is responsible for and makes the effort to complete said tasks on time and up to the expected standard. With the entire team functioning properly by taking responsibility for their own work, they can work together towards a common goal. Teamwork exists so that a group of individuals with a diverse set of skills and talents can work together to create something better than one could create on their own. It is crucial to work with other teammates to share ideas, improve each other's work and help one another to form a good team (Indeed 2019).

2.3.7 Tools

This section discusses and provides a short description of the specific purposes of a few tools that may be used in order to construct the upcycled bench.

2.3.7.1 Saws

A saw is used to cut materials to the size and dimension needed. Different types of saws are used to make different types of cuts (Merriam-Webster 2020).

2.3.7.1.1 Circular Saw

A circular saw is a power-saw using a toothed or abrasive disc or blade to cut different materials using a rotary motion spinning around an arbor (Houghton Mifflin Harcourt Publishing Company 2020). A circular saw is pictured in Figure 2-2, below.

Figure 2-2 A Makita brand circular saw.

2.3.7.1.2 Bandsaw

A bandsaw is an endless saw, consisting of a steel band with a serrated edge running over wheels. It can be used to cut metals and woods (Merriam-Webster 2020). A bandsaw can be seen in Figure 2-3, below.

Figure 2-3 A Makita brand bandsaw.

2.3.7.2 Power Drill

A power drill is a hand tool with a rotating chuck driven by an electric motor and designed to take an assortment of tools for drilling, grinding, and polishing (Collins 1979).

2.3.7.3 Impact Drill

Standard drills are primarily used for drilling holes, like the power drill, and driving in small fasteners. An impact driver's main purpose is to drive large fasteners. Long screws and, with the use of an adapter, lag bolts can be driven in more easily by an impact driver (Berendsohn 2019). Such drills are pictured in Figure 2-4, below.

Figure 2-4 Makita brand drills.

2.3.7.4 Screws

A screw is a short, slender, sharp-pointed metal pin with a raised helical thread running around it and a slotted head, used to join things together by being rotated so that it pierces wood or other material and is held tightly in place (Webster 2020).

2.3.7.5 Nails

A small metal spike with a broadened flat head, driven typically into wood with a hammer to join things together or to serve as a peg or hook (Webster 2020).

2.3.7.6 Welding machine

A welding machine is a device that provides an electric current to joint materials, usually metals or thermoplastics, by causing coalescence, most often by melting small parts of them (Glosbe). Pictured below in Figure 2-5 is a welding machine.

Figure 2-5 A welding machine.

2.3.7.7 Safety Glasses

Safety glasses are toughened glasses or goggles for protecting the eyes when using power tools or industrial or laboratory equipment (Webster 2020).

3 Alternative Solutions

3.1 Introduction

Section 3 is composed of the brainstorming process which led to the alternative solutions to satisfy Zane Middle School's need for student seating near the pickup area. The possible solutions are described generally, with the formulation of specific details reserved for the discussion of the chosen design.

3.2 Brainstorming Process

The alternative solutions generated are listed below. Detailed descriptions follow.

- Tire Benches
- Boulder Benches
- Suspended Tree Benches
- Single Seats
- Hammock
- Wall Benches
- Bench with Arm Rests
- Rebar Bench

3.2.1 Tire Benches

The tire is a ring-shaped component of a car that goes around the rim of the vehicle. Tires are used daily and are made of rubber recycled material that is highly durable and non-biodegradable. There is an abundance of tires, both new and used, since there are so many vehicles on the road and tires must be changed once their tread is worn down to a certain level. They could be used alternatively for seating. By burying half of a tire in the ground with the other half exposed above the ground, tires could be implemented as a resourceful seating solution. Tires are very low-maintenance and would be able to seat many people, depending on how many were installed. This type of seating solution is extremely resourceful and provides a very low-cost bench. A tire-bench diagram is pictured in Figure 3-1, below.

Figure 3-1 A tire bench diagram. By Hayden Miller.

3.2.2 Boulder Benches

A boulder is a huge rock that has been formed by the earth. Boulders are typically too difficult for one person to move, ensuring stability. They are big enough to provide sufficient seating for one or more people, depending on the size. They can also be part of a landscaping project that can provide natural-looking seating. Though they are not the most comfortable to sit on, boulders would be extremely cost efficient if they were implemented as a seating solution. A boulder "seat" is pictured below in Figure 3-2.

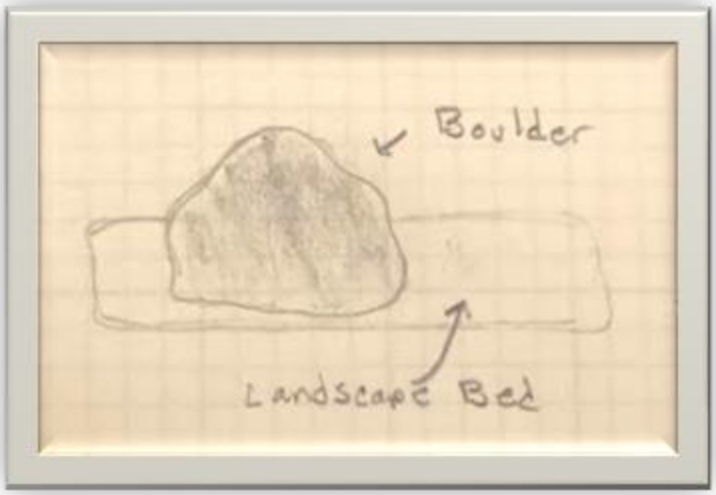

Figure 3-2 A boulder seating solution. By Hayden Miller.

3.2.3 Suspended Tree Benches

Another possible solution would be to create a bench that can be suspended from a tree or another sturdy overhanging object that could support the weight of a bench and 2-3 people. While a hanging bench would be aesthetically pleasing and has the perk of being rather fun compared to a static bench, the hanging bench comes with some irredeemable drawbacks. Hanging benches can pose a risk to the safety of adolescent middle schoolers due to the potential for a hanging bench to gain too much momentum when swinging. If misused, a bench pendulum could severely injure students. Another downside of the hanging bench is the need for an elevated anchor point. For this reason, this solution is not viable because the client would like for the bench to be located at the so-called Rectangle of Doom which is a featureless plane. A suspended bench diagram is pictured in Figure 3-3, below.

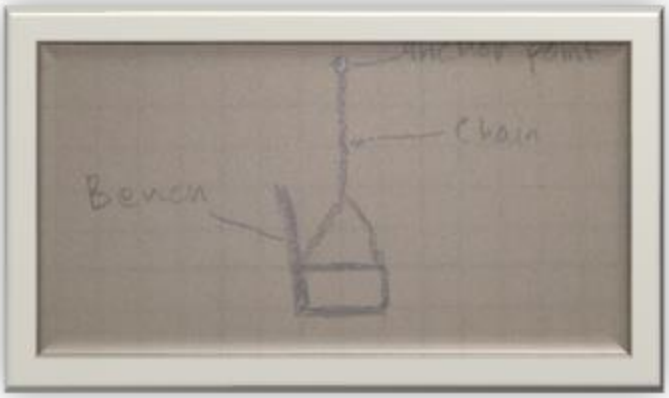

Figure 3-3 A suspended bench with chain support. By Nicholas Kenne.

3.2.4 Single Seats

Single seating benches can be made out of any material and are easy to construct. The only issue is that there would only be seating for one person at a time and the seating solution would not be as visually-appealing as a traditional bench that seats more. Single seating benches could be better implemented indoors, like in a waiting area for an office. A single-seat diagram is pictured below in Figure 3-4.

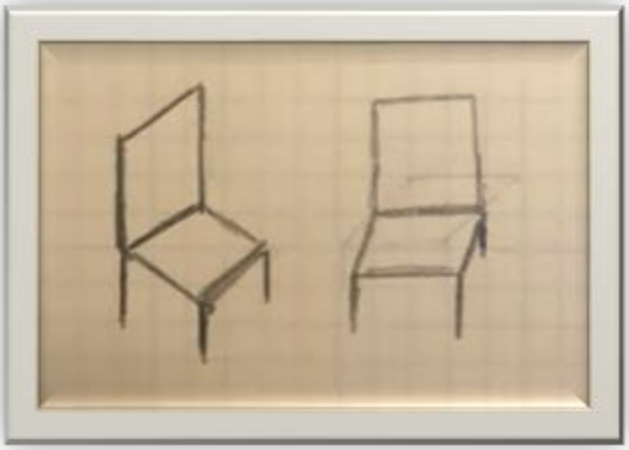

Figure 3-4 A single-seat diagram. By Andie Kolasinski.

3.2.5 Hammocks

Hammocks can be made out of a variety of materials, most commonly nylon or crochet. They are portable, comfortable, and flexible in terms of where they can be set up and how many people they can hold at once. Hammocks made out of nylon and paracord have high weight limits and do not break easily. On the other hand, they are made out of fabric and can hold water and later mold, which would pose a health risk. Installing hammocks at a middle school could create many safety concerns. Similar to

a suspended tree bench (detailed in Section 3.2.3), hammocks swing and kids could potentially fall out of them and get hurt. Also, the excess fabric of the hammock could create privacy that wouldn't be appropriate in a middle school context. A hammock diagram is pictured in Figure 3-5, below.

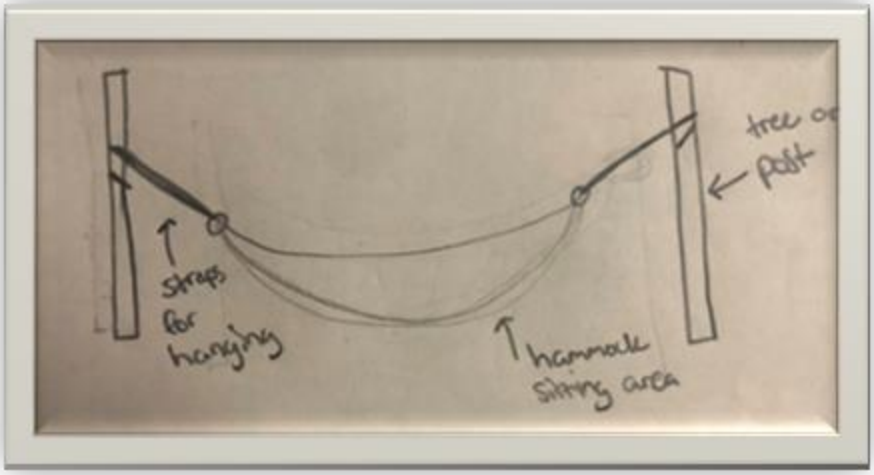

Figure 3-5 A hammock diagram. By Andie Kolasinski.

3.2.6 Wall-top Benches

A wall-top bench can be constructed by positioning seating atop an already-existing wall. This is an easy way to maximize space while providing seating without requiring pouring concrete or drilling into the ground. Wall benches can simply include a smooth surface on which to sit, or they can incorporate armrests or backrests. However, since people can sit on walls without a bench built into it, wall benches are not suitable for providing extra seating. Also, the walls at Zane Middle School are not positioned near the desired location for the new benches. A wall-top bench diagram is pictured in Figure 3-6, below.

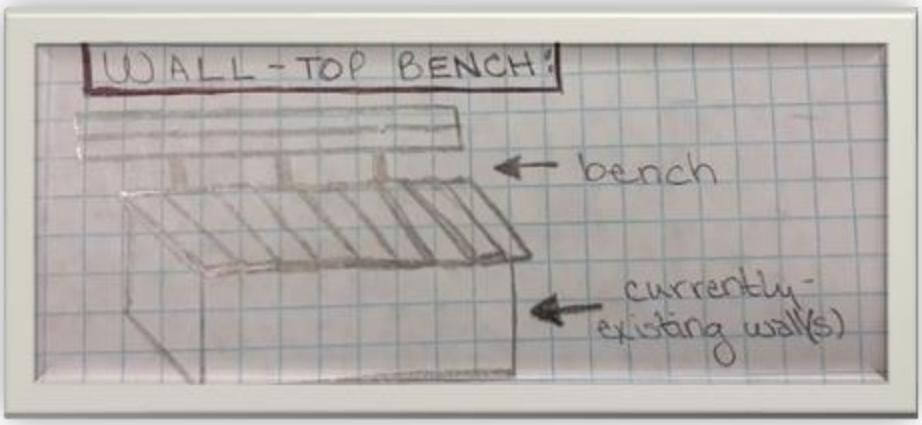

Figure 3-6 A wall-top bench diagram. By India Eichelbaugh-Goss.

3.2.7 Benches with Armrests

A standard bench can be made in two main ways with respect to armrests: with them or without. A bench with armrests can provide comfort as there is a place to rest forearms or elbows. Armrests can also work as an improvised table on which to place a binder and do homework, or to hang a coat. A bench without armrests can still provide comfort and a place to hang a coat by utilizing the bench's backrest. With the addition of arm rests comes an increase in cost, materials, and weight, while decreasing seating capacity by confining the sitting area. Arm rests act as a barrier and limit the capacity of the bench, allowing kids to only sit on it while facing completely forward. Kids would be unable to slide in on the side of the bench and increase capacity. Benches with arm rests feel closed off, formal, and unwelcoming, which is not the desired atmosphere. Pictured in Figure 3-7, below, is a diagram of a bench with armrests.

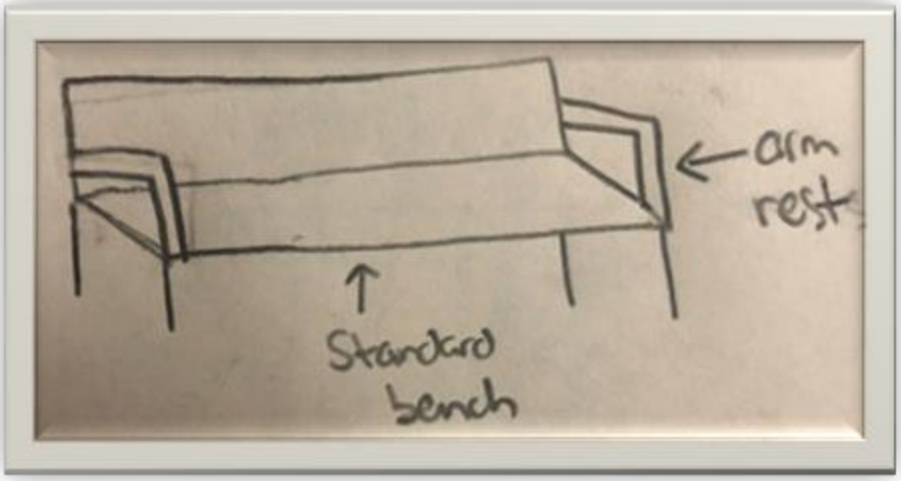

Figure 3-7 An armrest bench diagram. By Nicholas Kenne.

3.2.8 Rebar Benches

A bench with the frame constructed from recycled reinforcing bars is an attractive idea. Rebar is a cheap building material that provides structural integrity, typically used to strengthen concrete structures. Some types of rebar can also be reused. Building a bench frame from rebar would require welding the rebar together, but not all types of rebar should be welded. There are specific rebar alloys that should and should not be welded and determining the specific alloy of reused material could prove to be a tedious task. Naively welding unknown alloys could jeopardize the integrity and the safety of a bench.

4 Decision Phase

4.1 Introduction

Section 4 provides an overview of how the final design was decided upon. It reviews the criteria that was established early on in the design process and also considers each of the alternative solutions that were brainstormed by Team HANI. A Delphi Matrix is included, which quantifies how well each of the alternative solutions would meet each criterion. At the end is a discussion that justifies the selection of the alternative solution chosen for the final design.

4.2 Criteria

The following criteria are defined in Section 2.2.3. They were generated based on the specified needs of the client, and were weighted for importance and considered accordingly when choosing the final design.

- Safety
- Aesthetically Pleasing
- Upcycled
- Durability
- Cost
- Comfort

4.3 List of Alternative Solutions

The list of alternative solutions generated for this project are as follows:

- Street Sign Benches
- Tire Benches
- Boulder Benches
- Suspended Tree Benches
- Hammock
- Wall Benches
- Bench with Arm Rests
- Rebar Bench

4.4 Decision Process

The decision process consisted of presenting the alternative solutions to the client, receiving and considering his feedback, and accounting for each criteria and constraint. Eight alternative solutions were presented to the client, along with a list of criteria, each with its respective numerically-defined importance (weighted on a scale of 1-10) were presented to the client. The weighted criteria with constraints are shown in Table 4-1, below.

Table 4-1 Criteria and constraints with respective weights.

Criteria	Constraints	Weight (scale of 1-10)
Safety	Meets or exceeds school district standards	9
Aesthetically Pleasing	> Onsite Benches	8
Upcycled-ness	> 50%	7
Durability	Equal to onsite benches	7
Cost	< $400	6
Comfort	> Onsite benches	6

A Delphi Matrix was used to evaluate the ability of each alternative solution to meet each criterion. The scale used was 0-50, with 0 indicating that the design was not very likely to meet the criterion, and 50 indicating that the design was very likely to meet the criterion. At the bottom of each column, the values for each design were summed to show which designs are most and least likely to satisfy the design criteria. The Delphi Matrix is shown in Table 4-2.

Table 4-2 Delphi matrix used to decide between alternative solutions.

Criteria	Weight 0-10 high	Alternative solutions (0-50 high)							
		Tire Bench	Boulder	Suspended	Hammock	Wall Top	Arm Rest	Street Signs	Rebar
Safety	9	40 / 360	20 / 180	15 / 135	15 / 135	40 / 360	40 / 360	40 / 360	35 / 315
Aesthetically Pleasing	8	30 / 240	45 / 360	50 / 400	40 / 320	35 / 280	30 / 240	50 / 400	20 / 160
Upcycled-ness	7	50 / 350	0 / 0	20 / 140	20 / 140	40 / 280	40 / 280	50 / 350	25 / 175
Durability	7	45 / 315	50 / 350	25 / 175	10 / 70	40 / 280	30 / 210	40 / 280	35 / 245
Cost	6	50 / 300	50 / 300	50 / 300	50 / 300	50 / 300	50 / 300	50 / 300	40 / 240
Comfort	6	35 / 210	20 / 120	25 / 150	30 / 180	35 / 210	45 / 270	40 / 240	20 / 120
Total		1775	1310	1300	1145	1710	1660	1930	1255

4.5 Final Decision Justification

As shown in Table 4-2, the Street Sign Benches received the highest Delphi score and will be implemented as the final design. This design scored highest for each criterion with the exception of comfort. The Street Sign benches will be very safe for middle schoolers to use due to their sturdiness and smooth surfaces. Out of all of the designs, the Street Sign benches scored highest for their aesthetic value. The design will provide Zane Middle School with a bright and colorful aesthetic that can easily be achieved by using a variety of signs. They will also be very durable due to the weather-resistant feature of street signs; however, because of their upcycled nature, their durability may be slightly compromised. The Street Sign Bench design received a slightly lower score on comfort than did some other options but this is acceptable because these benches are not intended for prolonged use, but rather for waiting for a few minutes.

5 Specification of Solution

5.1 Introduction

Section 5 describes in detail the upcycled bench which was implemented at Zane Middle School. This section contains a complete description of the design, along with instructions for implementation of the bench. Analyses of the material costs, labor, and the expected cost of maintenance are also included in this section. The results of prototyping and testing are included at the end of this section.

5.2 Solution Description

As discussed in Section 4.5, the Street Sign Bench was decided upon as the final design for the upcycled bench project for Zane Middle School. The bench is made entirely out of upcycled materials, including galvanized steel pipe, a perforated metal sheet, rivets, flanges, and street signs. The bench is 48” long and 33” tall, with the seat 15” above the ground. The seat is 18” from front to back, and the backrest is 18” tall. The final design is shown in Figure 5-1, below.

Figure 5-1 The final design of the Upcycled Bench. By Hayden Miller.

5.2.1 The Frame

The bench frame is made out of galvanized steel pipe (Figure 5-2, below). The client was wary about the incorporation of galvanized steel into this project since the coating of the steel can release toxic chemicals when heated. However, the upcycled bench's frame was welded by Miller Farms, whose employees are experts in welding such material and were able to avoid all potential dangers. The frame is very sturdy and features an extra support beam that runs parallel to the length of the bench seat between each edge.

Figure 5-2 The upcycled frame. By Hayden Miller.

5.2.2 The Perforated Metal

The perforated metal sheet used in this project had dimensions of 40" by 54". The purpose of the perforated metal is to add strength and support to both the seat and the backrest of the bench.

5.2.3 The Rivets

In order to attach the perforated metal to the bench frame, and then to attach the street signs to the perforated metal, a total of 54 steel rivets were used. To attach the rivets, a pop rivet gun was used. The rivets are the only new and non-upcycled material that went into this project, and the reason for this is safety. Since rivets are used to ensure the sturdiness of the bench and essentially hold the entire bench together, no risks that would potentially compromise the bench's sturdiness could be taken by repurposing used rivets.

5.2.4 The Flanges

Four steel flanges were used in the final upcycled bench design. Each flange had a hole drilled through it so that a lag bolt could later be used to secure the bench to the ground. Each flange is 3" by 2".

5.2.5 The Street Signs

The street signs used for this project are upcycled engineering-grade traffic signs. The largest of these is a previously-octagonal, now-hexagonal, stop-sign which is used as the main backrest. Also used to make the seat and backrest portions of the bench are 6 small rectangular signs, all of which are 12" by 18". Such signs typically retain their reflective quality for 5-7 years outside, and due to the strategic design of this bench the signs are interchangeable, in case the client wants to replace the signs if they fade. Not only do the signs provide a vibrant aesthetic which matches Zane Middle School's school colors, but they also provide an extra layer of tensile support to keep the perforated metal from sagging when sat on. Some street signs that were donated to Team HANI to utilize in the Upcycled Bench Project can be seen in Figure 5-3, below. Not all of these were used in the final design.

Figure 5-3 Various street sign donations. By India Eichelbaugh-Goss.

5.3 Cost Analysis

This section provides an analysis of the cost of designing and implementing the upcycled street sign bench at Zane Middle School. The final cost is the culmination of the total hours and capital spent on research and designing the system, acquiring materials, and prototyping and building the final design.

5.3.1 Cost of Labor

In this section, the cost of labor is measured in hours. During the overall design and implementation process of the upcycled bench, the majority of the labor hours were spent on documentation of the project. This included writing out sections including the literature review, problem analysis, alternative solutions, and the final decision. Implementation of the solution consisted of building the structure and transporting it to the client's home (so that it could later be secured to the concrete at Zane Middle School), and required 4 hours of construction and one day for transportation. Implementation and construction were the least time-intensive processes (detailed in Section 5.4), followed by prototyping (detailed in Section 5.5). A total of 127 hours was spent on this project, and a visual breakdown of labor hours spent on this project is shown in Figure 5-4, below.

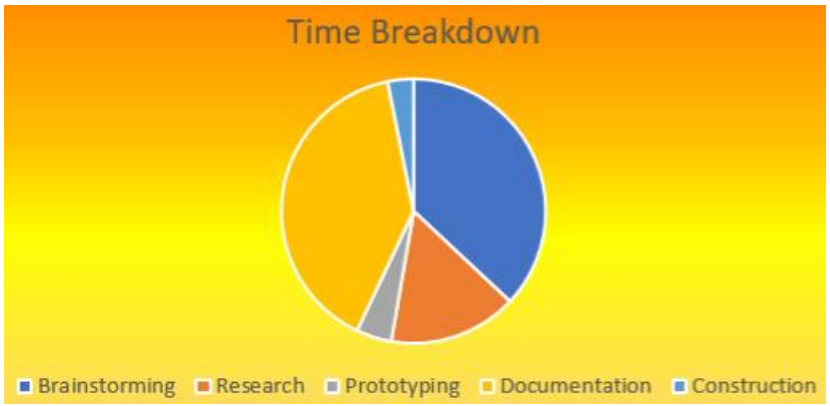

Figure 5-4 A pie-chart representing time spent on this project. By Nicholas Kenne.

5.3.2 Cost of Implementation

The total cost of materials for the bench was $00.00 due to many generous donations. The total sum of the cost of materials ($00.00) is under the budget of $400, so the criterion for cost was met. The itemized list of materials used and the respective capital donors are shown in Table 5-1, below. Note that retail prices are listed; this is to indicate how much money was saved during this project.

Table 5-1 Table of donations.

Item or Service	Retail Price	Donor
Six rectangular street signs	$120	Town and Country Mobile Villa
One large stop sign	$40	Miller Farms
Welding and construction	$1,000	Miller Farms

5.3.3 Cost of Maintenance

The cost of maintenance for this project will be very low. Material parts are not expected to need replacement due to their durability, but the street signs may be interchanged for aesthetic purposes, if desired. In the case that signs are to be interchanged, as proven by the cost of implementation this can be done for free by sourcing and obtaining used street signs. The only cost associated with this maintenance would be for purchasing new rivets; a 100-pack of steel rivets can be bought for slightly over $20 from various hardware stores or online hardware supply shops.

5.4 Implementation of the Design

This section will lay out instructions on how to build, set up, and maintain an upcycled street sign bench.

5.4.1 Building Steps

This section will detail the building instructions for an upcycled street sign bench.

5.4.1.1 Gather materials.

The first step in building an upcycled street sign bench consists of gathering the needed materials. This specific design requires one large stop sign and six 12" by 18" rectangular signs. It also requires a sheet of perforated metal that can be wrapped around the bench frame (the sheet used for this project was 40" by 58"), along with various lengths of galvanized steel pipe, depending on the desired bench size. For the frame, there should be 4 galvanized steel pipes of one uniform length for the legs (for example, 15-18"), 4 of another uniform length for the lengthwise back and seating supports (for example, 48-56"), 2 of another uniform length for the height of the backrest (for example, 18-20"), and 2 of yet another uniform length for the width of the seating portion of the bench (for example, 18-20"). 54 rivets will be needed for the attachment of street signs, and four flanges, each with a hole for a lag bolt, will be needed for stability. Some of the materials used in the construction of this project are shown in Figure 5-5, below.

Figure 5-5 Some materials needed to construct an upcycled street sign bench. By Hayden Miller.

5.4.1.2 Gather tools.

Next, tools will need to be gathered in order to construct an upcycled street sign bench. The tools that are needed consist of drills, a welding machine, a soft rubber mallet, and a pop rivet gun. If galvanized steel pipes are not already cut to the desired dimensions, a measuring tape should be used to measure them out, and then a bandsaw may be used to make the needed adjustments. Some of these tools are pictured in Figure 5-6, below.

Figure 5-6 A few tools used for the construction of the upcycled bench. By Hayden Miller.

5.4.1.3 Weld the frame.

After gathering the necessary materials and tools, construction of the bench can begin. The first step of constructing the bench is welding the frame. Of course, a welding machine will be required for this step. Pictured below in Figure 5-7 is the fully-welded frame used in this project.

Figure 5-7 The galvanized steel frame. By Hayden Miller.

5.4.1.4 Add the perforated metal sheet.

In order to provide more sturdiness than would be offered by using street signs alone, a perforated metal sheet must be attached to the bench frame. This can be done easily by molding the perforated metal around the frame of the bench using a soft rubber mallet. The bench frame with the perforated metal around it, as well as the mallet used to bend the metal, are pictured below in Figure 5-8.

Figure 5-8 Bending perforated metal around the frame. By Hayden Miller.

5.4.1.5 Add a flange to each bench leg.

In order to help ensure the stability of the bench when installed, a flange must be added to the bottom of each leg. The flanges should have a single hole drilled into each one so that lag bolts can be drilled through these holes and used to secure the bench to concrete upon installation. Such a flange can be seen in Figure 5-9, below.

Figure 5-9 A flange attached to a bench leg. By Hayden Miller.

5.4.1.6 Attach street signs using rivets.

The street signs provide both a pleasing aesthetic as well as extra tensile strength to the upcycled bench design. In order to provide more creative freedom by making the signs interchangeable and to eliminate the use of sharp screws that could protrude from the bench and injure students, rivets can be used to attach the signs. A total of 54 rivets were used in the construction of this project. Figure 5-10, below, shows the perforated metal-wrapped bench frame with one street sign attached.

Figure 5-10 Adding signs onto the perforated metal on the bench frame. By Hayden Miller.

5.4.2 Initial Setup

Once the bench is fully constructed, with all street signs securely attached, it is ready to be set up and implemented. The bench should be placed on a level surface, and this particular design is meant to be drilled into the concrete. Four lag bolts will be needed for the purpose of securing the bench to the concrete; one will be drilled through the hole in each flange. Once the lag bolts have been drilled into the concrete and the bench is stationary and stable, it is ready to be used.

This particular bench will be installed in the concrete in front of the "Rectangle of Doom" at Zane Middle School so that it is visible upon arriving at the campus.

5.4.3 General Maintenance

The upcycled street sign bench will require very little maintenance, projected to be only once per year, if that. This yearly maintenance will include checking the tightness of the rivets to ensure that the signs are still being held to the bench securely; this can be done by simply attempting to wiggle the rivets. If the rivets have become loose, they may be replaced using a pop rivet gun.

Another instance where yearly maintenance may be required is in the case that the bench gets dirty. If the bench is visibly dirty, it may be wiped down with a moist rag or towel.

Optional maintenance that will provide the opportunity to update the aesthetic design of the bench can be done as well, as frequently or rarely as desired. This bench design allows the street signs to be removed and replaced with new ones. To achieve this, a rivet removal tool will be required to remove the rivets securing the current signs, and a pop rivet gun as well as new rivets will be needed to attach the new signs. Reusing rivets is not recommended due to their important role in providing sturdiness.

5.5 Results of Prototyping

Three out of five prototypes used to develop the design of the upcycled bench were successful in shaping the final design of the project. Two of these prototypes demonstrated functional aspects of the final design. Three possible aesthetic designs for the final product were prototyped, and one of these determined the final design.

To provide a prototype for weather resistance, sturdiness, and durability of the type of weld and flange that will hold the bench in place, a flange installed for another project three years prior (Figure 5-11, below) was tested by observing its condition after three years of continuous use. This functioning prototype served to demonstrate the durability of the weld type for the flange used in the final bench design.

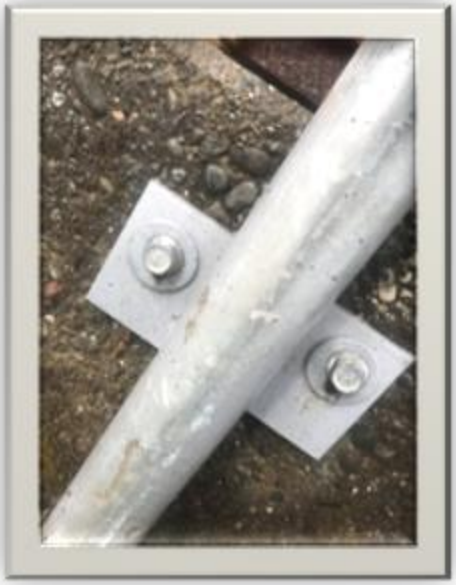

Figure 5-11 Welded flange prototype used to test function, sturdiness, and durability. By Hayden Miller.

Figure 5-12 below, shows a very similar flange that serves the same function as the prototype shown in Figure 5-11, above. The second prototype was considered because it was thought to be able to provide a sturdier foundation for the bench, but was decided against due to the tripping hazard its larger dimensions could present. Also, a flange with a single hole would make it easier to ensure that the bench would be level, according to Hayden Miller.

Figure 5-12 Another flange prototype. By Hayden Miller.

To prototype the aesthetic value of the upcycled bench, two miniature benches were constructed using a variety of paper scraps, business cards, plastic credit cards, cue tips, and duct tape. The first miniature bench is shown in Figure 5-13 and was tested by presenting the photo to and receiving feedback from the client, who suggested a design alternative that included fewer, larger signs.

Figure 5-13 First prototype for desire, demonstrating aesthetic value, and an overview of the bench. By India Eichelbaugh-Goss

The second prototype for the aesthetic value of the bench was another miniature bench (Figure 5-14, below). The client's feedback from the first miniature was considered when designing this, and once the prototype was completed both miniatures were presented to an audience of 11 people who were asked to vote on the bench they preferred. As a result, 5 people voted for the first prototype, and 6 people voted for the second prototype.

Figure 5-14 The second prototype for desire based on client feedback, demonstrating geographically-relevant aesthetic design as well as a lower demand for materials. By Andie Kolasinski.

Although the second prototype with fewer signs won the vote during its testing period, the final design is modelled by a third prototype with a higher quantity of smaller street signs as well as a stop sign (Figure 5-15, below). This design was decided upon because smaller signs were already in the team's possession at the time of construction and, due to mandatory social distancing practices as a result of COVID19, it was decided that further sourcing of materials would not be necessary.

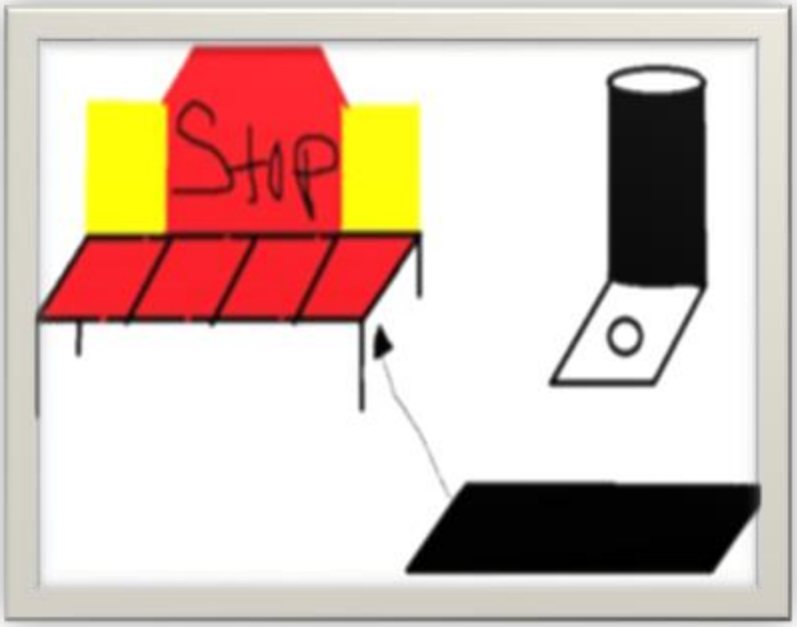

Figure 5-15 Third prototype for aesthetic value, with a few ideas for functionality. By Hayden Miller.

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