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1 Problem Formulation

1.1 Introduction

CBL Designs' first section of the design project document, the problem formulation, contains an objective statement and a black box model. The objective statement is used to identify the mission and offer a solution, the black box model shows a simplified breakdown of the team's problem, and the result on the classroom after the project is completed.

1.2 Background

The client is Teresa Pambianco, a special education class teacher at Zane Middle School. Zane Middle School is the largest middle school from the area between San Francisco to Eugene, it serves roughly 600 children from grade 5-8. Her classroom reaches a maximum size of fourteen students.

1.3 Objective

The objective of this project is to design and build a safe indoor planter box that allows students to view the below-ground portion of common rooting vegetables. The client is Teresa Pambianco, a special education class teacher at Zane Middle School. Her classroom reaches a maximum size of fourteen students. The design will include appropriate drainage components to allow for adequate soil drainage. The final design will be based off of classroom-specific size parameters and other parameters defined by the client.

1.4 Black Box Model

The black box model shown in Figure 1.1 shows the input, which is the state of the world before the project's completion, and the output, which is the state after the project is finished.

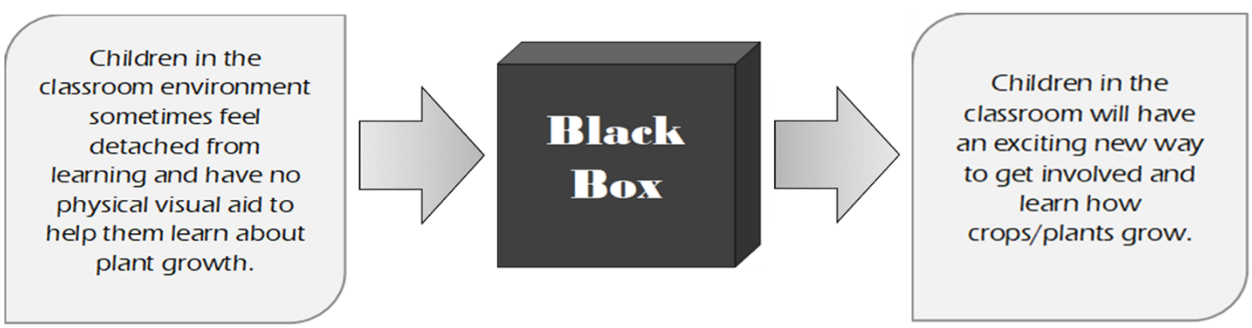


Figure 1.1: Black Box Model demonstrating the inputs and outputs of the design process.

2 Problem Analysis and Literature Review

2.1 Problem Analysis

The problem analysis section discusses the specifications, considerations and constraints that were identified during the development of the design for the wall cutout garden. These were developed through discussion among the team along with numerous discussions with the client representative. This section continues to elaborate on criteria, usage, and the production volume of the project are also discussed in the section. These elements were created to serve as metrics, that the team could use to effectively evaluate various design alternatives.

2.1.1 Specifications

Specifications are factors that must be implemented into the design of the project. The specifications for The Wall Cutout Garden include:

- The project must be child safe, with no sharp edges and no small objects
- Must drain water and cause no water damage and/or leakage.
- Must weigh less than 100 lbs.
- 46 inches long and 6 inches thick.
- Be capable of growing plants with rooting structures.
- The product must be durable.

2.1.2 Considerations

Considerations are elements that create context for the project and are developed alongside the client. They include:

- Potential exposure to allergens.
- Potential exposure to sensory triggers including:
  - Strong smell.
  - Vibrant colors.
  - Excessive, bright light.

2.1.3 Criteria

Criteria	**Constraints**	Ranking/Weight (High (10) to Low (0))
Safety	Must be safe for anyone operating the planter under normal use.	10
Functionality	Must be able to grow root crops without fertilizer.	10
Durability	Must withstand accidental knocks and pushing/pulling by students. Cannot be easily knocked loose from wall cutout.	9
Cost	Must be limited to $400 for the project ($75 per person and $100 from the school).	8
Maintenance	Must require occasional watering and draining no more than once per week. Only	8

	requires watering and draining once per week.	
Aesthetics	Must be visually appealing to the students	7
Environmental Impact	Must have at least 25% reusable materials.	6

Figure 2.1: Table of Criteria and Constraints and their associated weights.

2.1.4 Usage

The wall cutout garden will be used as an educational supplement in the client representative's classroom to allow students to observe aboveground and belowground plant growth. It will be designed to allow students to look through a window into a planter box and see the plants root structures, reinforcing classroom lessons on plant growth. The wall cutout garden will be designed to last at for at least 5 years without significant replacement of componets.

2.1.5 Production Volume

One root garden will be produced for use at Zane middle school. However, in the event of a successful project, the plans may be used to produce more units in a simple and streamlined manner.

2.2 Literature review

2.2.1 Crop Species:

This section gives an overview of various crops that the project may be used to grow. The primary focus of this section is to look at optimal growing conditions for each crop. Time to harvest is not analyzed since this is dependent on environmental factors. The following species were chosen for analysis based on the client interview.

2.2.1.1 Carrots

Carrots are a commonly eaten root vegetable. They are in the family Carrot family (Apiaceae), and their genus is *Daucus*. They are grown in a wide range of temperatures throughout the world, but generally do best where temperatures range from 59 degrees Fahrenheit to 64 degrees Fahrenheit. There are at least eight different varieties of commonly grown carrots, including the Chantenay type, which is the "mainstay of many commercial producers". Optimal soil pH ranges from 6.5 to 7.5. Carrots are cool weather vegetables that need about 0.8 inches of rainfall per week when grown outdoors (carrotmuseum). Often, radishes and carrots are geminated together (World Carrot Museum, 2006 and Baldwin et al., 2012).

2.2.1.2 Radishes

Radishes are also a commonly eaten root vegetable. They are closely related to turnips and rutabagas, all of which are in the mustard family (Brassicaceae) and the genus *Brassica* (Baldwin et al. 2012). Radishes are grown in a wide range of conditions, but "grow best when daytime temperatures are below 75 degrees Fahrenheit" (Zandstra and Warncke, 1989). They are fairly easy to grow, and some types of varieties excel in window conditions (Daniels, 2015). Ideal soil pH is from 6.0 to 6.5. Radishes prefer full sun as well as “loose, well-drained soil” (Daniels, 2015). Radishes germinate rather quickly, in just three to seven days (Daniels, 2015).

2.2.1.3 Onions

Onions are part of an extremely diverse genus of plants called *Allium*, in the family Alliaceae. The commonly eaten part of an onion is called the bulb. There are more than four hundred species of *Allium*. Onions grow well in a wide variety of environmental conditions, but do best in cooler, humid environments. Sets are generally used for growing green onions, while bulbs are usually from seed or transplants. Onions can grow in a wide variety of soil types, but well-drained soil with a lot of organic matter is ideal. Leeks, chives and garlic are all crops that are closely related to onions (Lerner, 2000).

2.2.1.4 Beans

Beans are part of the bean family (Fabaceae), and the genus varies from variety to variety. They are a warm season plan, with the exception of the fava bean which tolerates cooler temperatures ranging from 60 to 65 degrees Fahrenheit. Beans are nitrogen-fixers, which means they will add nitrogen to the soil, helping to create ideal growing conditions for other plants. However, they do not begin fixing nitrogen until they have a well-established root system (Relf et al., 2015). Common varieties of beans that are grown and consumed include: snap beans, half-runner beans, pole beans, lima beans, southern peas, soybeans, and dried beans. Beans are also “fairly tolerant of a wide range of soil” conditions, though they prefer soil pH to be within 5.8 and 6.5 (McCormack, 2004).

2.2.2 Lighting:

This section gives an overview of the various types of indoor lighting solutions, and elaborates on their characteristics in terms of their effectiveness, availability, and cost. Various wavelengths and types of light are important to plants, and different types of lighting deliver different proportions of these wavelengths (Trinklein, 2002). Yellow and green light is the least important part of the visible spectrum, while red and blue light is exceedingly important for plant growth (Trinklein, 2002).

2.2.2.1 Natural:

Sunlight can serve as a quality source of light for indoor plant propagation, depending on availability. Sunlight delivers an ideal profile of wavelengths for plant growth, depending on the location in the world. Larger, south facing windows are ideal for taking advantage of natural light, and east or west facing windows may be suitable depending on their exposure level. In North America, North facing windows are generally not suitable for indoor plant propagation (Anderson, 2004).

2.2.2.2 Incandescent:

Incandescent lighting is limited when it comes to indoor propagation of plants. They produce an ample amount of red light but also produce a limited amount of blue light. Furthermore, they produce a lot of heat, which generally requires them to be placed at a larger distance from the plants. Finally, incandescent lighting is relatively energy intensive, compared to other lighting options (Trinklein, 2002).

2.2.2.3 Fluorescent:

Fluorescent lighting is a commonly used solution for indoor plant lighting. It produces a broad spectrum of light, fulfilling plants’ needs of red and blue light. Plants grown exclusively under fluorescent lighting will require about 2 hours of artificial light for every hour of required natural light, meaning that plants will require lighting for about 16 hours per day (Miller and Dunn, 2016). Fluorescent bulbs are fairly energy efficient and last, on average, for about 10,000 hours of use. Fluorescent lighting is widely available and relatively cheap compared to other options (Trinklein, 2002).

2.2.2.4 LED:

Light emitting diode (LED) lighting is emerging as a popular method for providing light to indoor plants. LED lighting is more energy efficient than fluorescent lighting and emits less heat. They can last up to 50,000 hours versus the 10,000 hours expected from fluorescent systems. LED lighting can emit various combinations of spectral outputs, making it a highly versatile option. LED lighting is becoming more widely available, but maintains a higher initial cost compared to other lighting options (Mills, 2016).

2.2.2.5 HID:

High energy discharge (HID) lighting is a commonly used lighting form for more sophisticated indoor plant growing operations. HID lighting delivers a suitable spectral output for indoor plant growth. They generate more heat than their LED and fluorescent counterparts. They also cost more, with prices ranging from approximately $250-$500 for appropriate fixtures. Furthermore, the light generated by HID lighting may prove disruptive in a classroom environment because they are very bright (Anderson, 2004).

2.2.3 Soil

2.2.3.1 Organic Matter

Organic matter is a crucial component of soil that has numerous benefits to plant growth. It provides a "spongy texture" that increases the soil's water holding capacity. It also increases "pore space" within the soil, which allows for roots to engage in more efficient gas and nutrient exchange. During its decay process, organic matter can release nitrogen and other nutrients that plants can use, while also increasing the overall nutrient storage capacity of the soil. Common ways to boost soil organic matter include adding manure, compost, peat moss, peat-humus, mushroom compost, and composted sawdust. Another popular way of adding organic matter to soil is to grow cover crops when the garden bed is not being used for other plant growth. Though organic matter adds nutrients to soil, it should not be used solely in nutrient addition because it rarely supplies a balanced array of nutrients (Sellmer, 2017).

2.2.3.2 Manure

Dried animal manure is commonly applied to soil to provide a wealth of nutrients to the system. Common animal sources of manure include cows, chickens, and sheep. However, fresh manure should be mixed with phosphate fertilizer, lime, and/or superphosphate to ensure a balanced nutrient profile. Various manures are commonly sold at garden supply stores. Some manure can give off foul odors, depending on how fresh it is and how it was processed. (Sellmer, 2017)

2.2.3.3 Sawdust

Sawdust is often used as mulch in garden systems. Sometimes, sawdust can negatively impact soil pH, so limestone is often added in addition to sawdust to limit impacts. More commonly, sawdust can cause nitrogen depletion in soil because microorganisms will use soil nitrogen while decomposing sawdust; thus, nitrogen should be added to the soil alongside sawdust additions. (Sellmer, 2017)

2.2.3.4 Composts

Compost is a widely used addition to gardens. It is also a good way to get rid of previous crops leftover organic matter. Composting is a process that is done over time, with the addition of existing soil, fertilizer, and moisture. Over time the organic matter breaks down into compost that is useful to add to gardens. (Sellmer, 2017)

2.2.3.5 Soil pH

Soil pH is a measurement of how acidic or basic a soil's content is. Soil pH can affect the availability of nutrients to plants and can impact how effectively plants can uptake nutrients. Soil pH can be tested. Many plants grow well in slightly acidic soils, ranging from 6.2 to 6.8. Adding lime to soil can help to neutralize soil acidity. If lime needs to be added, as indicated by a soil test, then it should be added several months prior to planting because changes in soil pH happen gradually over time (Sellmer, 2017).

2.2.3.6 Soil Nutrients

The primary nutrients that affect plant growth are nitrogen, phosphorus, potassium, magnesium, and calcium. Many soils are listed with respect to their ratio of nitrogen to potassium to magnesium, commonly referred to as N:P:K (Sellmer, 2017).

2.2.3.7 Inorganic Fertilizers

Inorganic fertilizers are solutions prepared from mineral salts. They are often cheaper and more easily stored than their organic counterparts. However, they are very easy to apply, which makes over-fertilization a possibility. Furthermore, since the solutions are liquid, they may be easily lost from the root zone due to leaching. Leaching is when water draining through the soil removes soil nutrients (Sellmer, 2017).

2.2.4 Understanding Transportation

2.2.4.1 Inertia

As described by Newtons first law of motion, inertia is the tendency of an object in rest to stay in rest, or as the resistance of an object to change its state of motion. A body with greater inertia means more force is required to get the object to start moving. ("Inertia and Mass" 2019)

2.2.4.2 Rollability

Rollability is defined as the capacity to roll or be rolled; ease of rolling. (Oxford, 2019) Rollability directly relates to the hardness of a wheels/casters tread. A harder tread allows for a higher rollability, and therefore an easier to roll wheel. A low durometer reading, or a softer wheel, will have a larger initial inertia, requiring a larger initial effort to move. (Titizian, 2015)

2.2.4.3 Surface area & friction

As stated in *Physics 1 for dummies: 2nd edition*, "The force due to friction is generally independent of the contact area between the two surfaces." While one might expect that a greater surface area would cause a greater frictional force between an object and the surface it rests on, the force due to friction will not change as you still have the same weight pushing down on the surface from you given object. (Holzner, 2016)

2.2.4.4 Center of gravity & weight distribution

Weight distribution is the amount of the total load weight imposed on the ground at an axle, group of axles, or an individual wheel. Center of gravity is a point of an object's average location of weight. In uniform gravity, it is the same as the center of mass. The center of gravity of an object will be determined by the load distribution, a load with an uneven load distribution will have a center of gravity offset from the center of the load. Off-balance loads caused by an offset center of gravity can result in unequal strain between wheels. (Toner, 2011)

2.2.4.5 Hardness

Hardness is a physical characteristic of matter that describes its resistance to indentation, scratches, or compressive forces. Hardness is determined using a durometer, an instrument used to test the depth of an indentation in plastics and rubbers created by a force from a standardized presser foot. ("What is a durometer", 2019) (Penncoat, 2019) The hardness determined by using a durometer can be directly related to very important qualities of a wheel/caster.

2.2.4.6 Hard rubber wheels

Hard rubber wheels will allow for easy rolling and an increased load capacity. However, hard wheels could potentially dent softer flooring, so they are not recommended for hard wood, linoleum, or terrazzo. (Guy, 2016)

2.2.4.7 Soft Rubber wheels

Soft wheels offer good shock absorbance, a quiet ride, and greater floor protection compared to hard wheels. Under heavy loads, these tires can compress, making the load to be harder to push and decreasing the load capacity of the rig. (Guy, 2016)

2.2.5 Casters

2.2.5.1 Caster vs. wheel

Wheels are fixed and can only move on one axis, whereas casters are on a rotating mount and therefore able to move in more directions. Caster designs contain wheels in them, they're just wheels with extra bits built on for better functionality.

2.2.5.2 Rigid casters

A wheel mounted between two forks that will not rotate, allowing only forward and backward movement. These casters are stronger than casters that can swivel, so they are able to carry more weight. Certain rigid casters can be formed to maximize load capacity while remaining functional. For example, you can mount four rigid casters in a diamond pattern with the center wheels slightly larger than the front and back, so the truck can rotate on the center wheels. (Equipment 2019)

2.2.5.3 Swivel casters

Swivel casters are wheels mounted on ball bearings. They are capable of a full range of movement, meaning the cart can immediately make changes in all directions. It can be more difficult to initiate movement using these casters as the wheels must be all orientated in the same direction. It can also make it difficult for the load to be rolled in a straight line. (Equipment 2019)

2.2.6 Caster combinations

2.2.6.1 Three swivel casters

Minimum number of casters but also lowest weight capacity. Does have very mobility and is easily maneuverable. (Equipment 2019)

2.2.6.2 Two rigid/Two swivel

Systems employing two rigid casters in combination with two swivel casters provide good maneuverability while still allowing the load to be pushed in a straight line. This system has moderate weight capacity, and can be enhanced by adding swivel casters with the ability to lock, creating an all rigid caster experience. (Equipment 2019)

2.2.6.3 Four Swivel Design

Systems using four swivel casters make for easy movement in all four directions. This design can be altered using four swivel locks. Using four swivel casters makes initial turning movements difficult due to the fact that all four wheels must be pointed in the same direction for effective turning (Equipment 2019).

2.2.6.4 Diamond mounted casters

Swivel in front and back, and rigid on the sides. This allows for turns on the center axis while also easily moving in a straight line, can have drawbacks on uneven surfaces. (Equipment 2019)

2.2.6.5 Tilt mounted casters

All rigid casters but the front and back casters are slightly smaller than the center casters, allows for better movement as you're only on three wheels at a time. Relatively low load capacity as well as difficulties of ramps. (Equipment 2019)

2.2.6.6 Anatomy of a modern caster

Figure 2.2 displays the internal components of a typical caster.

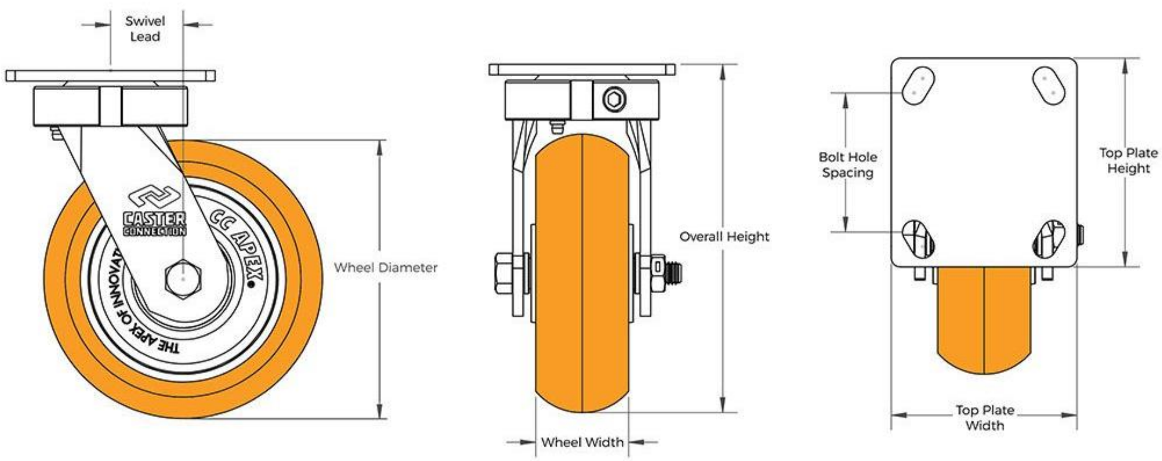


Figure 3.2: Image of the internals of a typical caster("ANATOMY OF A CASTER" 2019)

2.2.7 Fastening Mechanism

2.2.7.1 Latches

A latch is a mechanism with a metal bar and lever that raises and lowers out of a catch to allow a door to open to close. (Grannan 2016)

2.2.7.2 Thumb latches

- A plate that gets depressed by your thumb raises a latch arm on the inside which allows the door to swing open. When closing, the latch arm should rise and fall into the catch on its own, locking the door. (Grannan 2016)

2.2.7.3 Ring latches

- A ring is attached to a lever arm that resides in a catch, upon rotating the ring the arm is lifted out of the catch, allowing the door to open. Ring latches can be spring loaded or not spring loaded. (Grannan 2016)

2.2.7.4 Lever latches

- These are very similar to the ring latches in that you rotate a lever to lift a lever arm out of its catch allowing the door to open. (Grannan 2016)

2.2.7.5 Bolt latch

- A bolt resides in a catch to keep the door from opening, the bolt can be slid out of the catch in its track to allow the door to open. (Grannan 2016)

2.2.7.6 Fingertip release latch

- A simple latch with a bolt held back by a rotating arm that is lifted to let the bolt free and allow the door to swing open (Grannan 2016)

2.2.8 Latch materials

2.2.8.1 Iron

Iron latches are very durable and long lasting, though it can eventually rust, especially where the metal interacts with other metal. In coastal regions iron is not recommended.

2.2.8.2 Stainless steel

Stainless steel is mostly rust resistant, though it has a specific aesthetic quality.

2.2.8.3 Bronze

Bronze will not rust and is very solid and aesthetically pleasing, however, it can be expensive. ("Gate Latch Types - 360 Yardware" 2019)

2.2.9 Hydroponics

Hydroponics is the method of growing plants in a water based, nutrient rich solution. In a hydroponic system no soil is used, some medium such as perlite, rockwool, clay pellets, or peat moss. The premise is to expose the roots directly to the nutrients while also allowing access to oxygen. Hydroponics can allow for much faster plant growth, up to a 25% faster mature rate, and 30% more of the same plants grown. The plants will not have to work to obtain nutrients so it will grow faster and bigger. However, the plants will grow taller and will have a smaller root system. Careful control of nutrient solution and PH is required, the system uses less water than traditional soil plants. Hydroponic systems of any size will cost more than a traditional soil setup of the same size, they can also take a lot more work and time to setup. This system also requires much more maintenance as you must monitor your PH and nutrient levels on a daily basis.

2.2.9.1 Deepwater culture-

Roots are suspended in nutrient solution, with an air pump injecting oxygen into the system.

2.2.9.2 Nutrient film-

A continuous flow of nutrient solution flows over the roots of the plants, the flow allows a large amount of oxygen to run over the roots as well.

2.2.9.3 Aeroponics-

Roots of plants are misted with nutrient solution by either a pray mist nozzle or a pond fogger.

2.2.9.4 Wicking-

One of the easiest and lowest cost methods, you have a material medium, such as cotton, with a wick placed in nutrient solution, the solution can leach up into the medium and feed the roots.

2.2.9.5 Ebb & Flow-

A pump floods the root revisor with nutrient solution at certain intervals, then leaches out back into the holding tank, the pump is hooked up to a timer.

2.2.9.6 Drip system-

A slow drip provides a constant feed of nutrient solution to a hydroponic medium, feeding the system. ("Hydroponic Systems 101 | Learn The Basics of Hydroponics" 2019)

2.2.10 School Programs

2.2.10.1 Special Education

Is a section of education focused on students that have identified disabilities and provide instruction that meets their unique learning needs. Disabilities include mental disabilities and children that have been abused. These classrooms are made to create a less restricted environment such as; self-contained classrooms, assistive technology, accommodations, modifications, and paraprofessionals. Normally special education programs work in cooperatively with regular school programs to provide for the children. Programs are decided by the teacher to accommodate for the children unique learning capabilities. (Delegate Assembly of The Council for Exceptional Children 1983) Special education students learn in unique ways however most classes revolve around project-based learning. Having visual helps students understand a topic. (Team Understood)

2.2.10.2 STEAM

STEAM is a program schools implement to help encourage knew learning styles and encourage students to peruse science technology arts and math. It helps students learn 21st century skills and develop critical think ideas. While typical STEM is implementing math and science classes. Some schools use STEAM to help the support the arts. STEAM makes it a goal to relate the math and sciences to art to help creative idea but staying disciplined. (Danah 2014)

2.2.10.3 Common Core

Common Core is a description of skills that each student should have by each grade level that should be completed by high school. Pushed by governors and chief of states school officers at the 2009 summit in Chicago. Created for the purpose of raising standards in school and lower redemption courses in college. Common core results are collected by test for each grade level. (Gewertz, 2015)

2.2.10.4 Teaching techniques for Students with Learning Disabilities

Learning disabilities refers to an underdeveloped skill in one or more areas normally related to neurological disorders. Students with disorders can learn but consistently perform below average. Techniques include using earplugs during exams, large print test or novels, assistive technology, graphic organizers to present information, breaking down test into different sections, break down assignments into smaller parts, and using alternative formats of presentations. (Team Understood)

2.2.11 Disorders

2.2.11.1 Autism

Autism refers to a broad range of conditions characterized by challenges with social skills, repetitive behaviors, speech and nonverbal communication. Autism affects an estimated 1 in 59 children in the United States today. Because autism is a spectrum disorder, each person with autism is unique. The ways in which people with autism learn, think and problem-solve can range from highly skilled to severely challenged. Some people with autism may require significant support in their daily lives, some support or be entirely independent. Several factors may influence the development of autism, and it is often accompanied by sensory sensitivities and medical issues such as gastrointestinal disorders, seizures, sleep disorders. Also, mental health challenges such as anxiety, depression and attention issues. Symptoms appear at the age of 2 to 3. (*American Psychiatric Association, 2013)*

2.2.12 Container/Base Material

This section investigates various materials that the container and base of the wall cutout garden could be constructed from. Physical properties like water resistance, durability, and mobility will be analyzed for each material. Cost will also be discussed.

2.2.12.1 Wood

Wood is one of the more common materials used in building, if not the most common. Derived from various tree species, wood is comprised of cellulose, hemicellulose, and lignin, which holds all the fibers together (Woodford 2018). Wood is split into two categories: hardwood and softwood. This allows the material to be versatile and used for many different things. Hardwood is generally denser than softwood, so it tends to be used for higher quality construction work and furniture (Woodford 2018). Although softwood is often less dense than hardwood, some softwoods like redwood and cedar can still be used for building due to their stability and are a cheaper option than other hardwood. Since wood requires little work to process and turn into construction material, it is relatively cheap compared to most other materials. In addition to being cheaper, it is also lighter and more flexible than most metals and some plastics.

Some disadvantages in using wood as a material for building mainly comes from its tendency to degrade. Because it is a porous material made mostly out of cellulose, it can be prone to decomposition and rotting by mold growth, insect attacks, and water (King & Chen 2015). This can especially be detrimental to most woods in wet environments since they absorb and lose water easily which will eventually cause stress within the wood (King & Chen 2015). One way to offset this can be to use hardwood or dense softwoods to prevent much moisture from being absorbed. Additionally, pressure treatments or just coating the wood with treating agents can make the wood more resistant to water. Other treating agents can also be made to deter pests, prevent mold growth, provide stability in high or low temperatures, and/or increase durability (King & Chen 2015).

2.2.12.2 *Wood Plastic Composites*

Wood Plastic Composites, or WPCs, are materials made by mainly mixing together plant fibers and other wood-based fillers with polymers like polyethylene (PE), polypropylene (PP), or polyvinyl chloride (PVC). They are then molded under high pressure and temperature (Kaseem et al. 2015). Usually made from PE polymers because of its processing efficiency and the low temperature required to create them, WPCs are well known for their combined properties of both the wood and PE. They have advantages of a relatively low density, high versatility, and low cost in comparison with other building materials (Kaseem et al. 2015). They are also biodegradable and have an acceptable strength to survive an impact to the floor. The material is also water resistant which is enough for it to survive in damp places.

One disadvantage of the WPC can come from the poor compatibility between the wood and PE materials during processing. However, this can be solved by adding a coupling agent to combine the materials easier during processing (Kaseem et al. 2015). By combining the hydrophilic wood with the hydrophobic PE, the material can be more water resistant than just wood by itself (Kaseem et al. 2015).

2.2.12.3 *Styrofoam*

Styrofoam, also known as extruded polystyrene foam, is a man-made thermoplastic material that is mainly used for insulation. Because of this, it can be used as a planter and/or filler that is effective in keeping the temperature inside the container consistent (Writing 2017). It is also an extremely lightweight material that can make even large Styrofoam planters easy to carry. Additionally, Styrofoam is a great shock absorber because it is made of almost 90 percent air (Writing 2017).

Negative aspects of Styrofoam mainly come from the concerns of chemicals that can leach out if the Styrofoam container overheats (Harris 2018). However, under normal circumstances, especially indoors where it is usually room temperature, there should no risk of that happening. Another disadvantage of Styrofoam of course comes from its inability to degrade easily which can make it detrimental for the environment and makes it unable to be composted.

2.2.12.4 *Metal*

Substances that are made of metals like iron, steel or aluminum tend to be sturdier than most other materials and is often used for construction purposes. Materials like stainless steel, zinc, and copper can be used for planters (Jaques 2014). Disadvantages that often come from using metal in planters can be the heavy weight and risk of rusting. Unlike most other metals however, aluminum has a lighter weight and is still tough enough to withstand impacts from being dropped (Jaques 2014). Aluminum also doesn't rust which makes it ideal to use in wet conditions (Jaques 2014).

2.2.13 Window Material

This section will identify various types of transparent materials that are commonly used as types of windows. The main aspects covered for the materials are toughness and resistance to breaking. The relative safety of each material is also addressed, as well as the heat resistance to some.

2.2.13.1 *Glass*

Three types of glass that are commonly used as windows are annealed glass, tempered glass and laminated glass.

Annealed glass is the most average type that tends to break into large shards if broken (Glasscon 2015). Ordinary annealed glass can potentially be dangerous especially when it is broken into large, pointed shards that can cause injury. It can only be considered a safety glass if it is thick enough to resist shattering. Even then, annealed glass is prone to thermal stress which can cause further cracking (Josey 1997).

Tempered glass is a type of safety glass that is heat treated to be four to five times stronger and safer than annealed glass. The process involves heating to around 1,200 degrees Fahrenheit and cooling it rapidly (Glasscon 2015). Tempered glass, or toughened glass, are occasionally known to spontaneously break because of the inclusion of contaminants like nickel sulphide (NiS). Tempered glass is suspecptible to spontaneous fracturing when the cooling process happens too quickly and causes unstable nickel sulfide to grow and add internal stress into the glass (Josey 1997).

Laminated glass is another type of safety glass that puts one or more interlayers of polymer plastic material between two or more layers of glass to prevent shattering and scattering of glass shards (Glasscon 2015). If either glass layer is broken, the plastic polymer layer inside will keep the broken shards together and prevent injuries from happening.

2.2.13.2 *Acr*ylic/Plexiglass

Acrylic, or Polymethyl methacrylate (PMMA), is a scratch-resistant material that is often used as a replacement or alternative to glass. Also commonly known as Plexiglass, this material weighs less than 50% and 43% of both glass and aluminum respectively (Arkema 2006). It even lets more visible light through it than glass does at a high 92% light transmittance. Plexiglass sheets also have a greater impact resistance than tempered glass and are able to withstand being in lots of sunlight and other weather conditions (Arkema 2006). Acrylic glass can also be cut and drilled through which makes it ideal as a building material for windows and other parts for construction that are likely to be damaged at some point. It is important to use washers or countersinks when doing this to prevent any damage from being caused to the Plexiglass sheets. Countersinks also have the additional bonus of being able to have bolts sit flush with the material it is being screwed into to prevent risk of injury from the bolts sticking out. Although acrylic glass has good tensile strength and is quite flexible, putting too much strain on the acrylic sheets can cause fine cracks to form along the points of stress. This phenomenon, also known as crazing, can dull out the surface and make the material harder to see through.

3 Alternative Solutions

3.1 The Aquarium

The Aquarium Conversion alternative is a design that incorporates repurposing a commercially made aquarium. The conversion would involve adding a drainage system to the bottom of the aquarium as well as wooden framing for aesthetics and transport. The advantages of this design include widespread availability of sturdy commercially available glass aquariums. Glass designed to withstand hydrostatic forces would easily accommodate soil loads. Aquariums come in a variety of sizes, so finding one long enough would not be an issue; however, finding one to match the narrow depth (roughly six inches) of the wall cutout may prove challenging, as standard aquariums are usually a minimum of twelve inches (12") deep. A diamond tipped drill bit used for creating holes in glass could be used to create drainage holes in the bottom of the aquarium. A drainage catchment system would need to be installed on the bottom of the aquarium. The drainage catchment system would be made of Plexiglass and would be sloped to one side to allow for installation of a valve. This would allow for easy disposal of excess water. Finally, wooden framing could be incorporated to conceal the drainage system and meet the remaining dimensions of the wall cutout. Standard aquarium prices in sizes similar to the cutout are generally less than $300 but may be found on the used market as well.

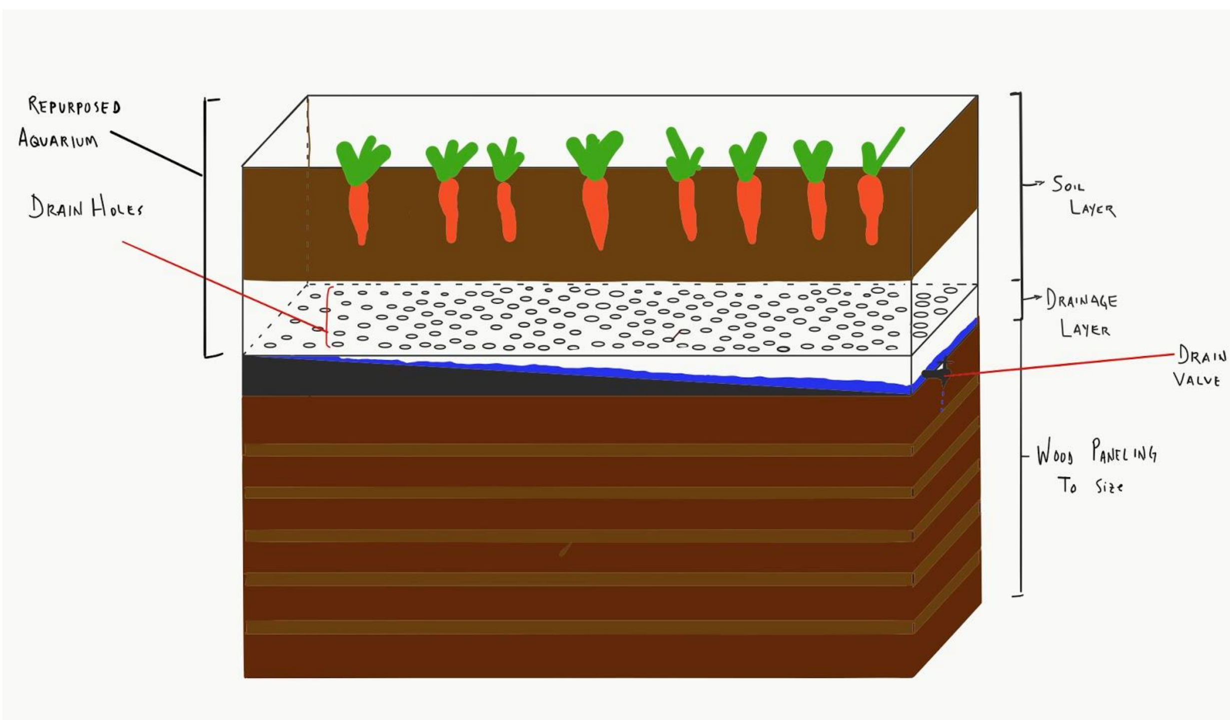


Figure 4:The Aquarium (Alternative solution drawing by Reed Crane)

3.2 Two-sided Glass Construction:

The two-sided glass construction alternative would involve construction of an aquarium-like structure to allow for viewing of the belowground portion of plants. The sides would be made from treated wood. The wood would be routed to the thickness of the glass, and then would be bounded to the glass using a bonding agent. The glass and wood construction would be study enough to accommodate the soil loads. Construction of such a system would allow for customizable sizing, which could prove useful in filling the wall cutout space in a precise manner. A sloped piece of glass or plexiglass would be installed on the bottom of the tank to facilitate directional water drainage. This would allow for installation of a plug or valve system to allow for easy disposal of excess water. The sloped glass would be supported with a wooden wedge and supports and would be bonded to the sides of the tank with a suitable bonding agent. The structure would be roughly six inches (6”) deep by thirty-six inches (36”) long by twelve inches (12”) tall. Glass panes in suitable dimensions are widely available and relatively inexpensive. The glass would need to be shatterproof to avoid potential safety concerns. Wooden paneling and framing would be incorporated to fill the rest of the wall cutout. Stains and designs would be applied to meet aesthetic requirements.

3.3 Integrated Lighting Alternative

The integrated alternative would match the design of another alternative but would include the addition of in integrated lighting system. A vertical wooden beam would be mounted to either side of the tank and extend approximately 28” above the top of the tank. This would allow for the installation of a fluorescent light hood and light bulb. The beams would include built in cable ties to allow for concealed cord placement. Fluorescent hoods and bulbs are widely available, relatively cheap, come in numerous dimensions, and are often available on the used market. Adding lighting would add expense to construction, but it would allow for greater plant growth potential.

3.4 Wood Framing

One option for the garden is to add wood framing around the edges, this would entail attaching slats of wood on all of the sides to create a strong and also aesthetically pleasing product. This alternative would be relatively cost effective, the team could most likely get some wood donated from local hardware stores. If the team wanted some higher quality pieces that would be stronger or prettier that may not be donated, such as purple heart, it would only cost about $20 for enough wood for the project. The border would add some weight, depending on what type of wood is used, a harder sturdier wood would add more weight, where as a softer alternative would be lighter. The addition of the border wouldn't require much work, it could easily be glued or screwed onto the vegetable tank. The border would also add some structural integrity to the project, this would help with the possible difficulties caused by the small width but long length of the structure. Additionally, it would be helpful in adding safety, by having softer corners that could be sanded down, along with a better chance of staying together in the event it fell or was knocked over by a student.

3.5 Metal Framing

Metal could be used in place of a wood frame; this would add greater strength but also more weight. A metal frame could have more variance in style than a wood frame, a wide array of colors and textures are available for use. These materials may be harder to get donated as they would be more expensive. However, it is possible to find used metals in scrap yards or something along those lines, as long as they are long enough for to take up an edge, as it would be difficult and most likely aesthetically pleasing if two sheets of metal were welded together. Metal is a much heavier alternative to wood, unless something very thin like aluminum was used, but with greater weight the material will have greater durability. A large addition to the overall weight could be a pretty bad thing, as mobility is an important factor in the project, metal framing would probably add too much weight to make the project easily mobile. On the upside, metal framing would make the project very strong and durable, it will be able to take much more of a beating from the kids and the structural integrity would be less of a problem thanks to the rigidity of the metal.

3.6 No Frame

An option is to simply not build a frame onto the project, this would mean just having a plexiglass rectangle that would most likely be completely transparent. This would have the advantage of being very lightweight, compared to having a frame, which would be very useful if weight and mobility becomes a problem. This alternative would have the weakest structure, as there would be no outside support, this would have to be supplemented with interior supports, such as carriage bolts. Obviously, this would be the most cost effective as no extra supplies would be required. Aesthetically, this model would most likely look very barren, and would not be very pleasing, unless the plexiglass that housed the soil and vegetables was altered to look better.

3.7 Separate Water Bin

An option for catching the water from the garden is to have it sit above a separate bin that will catch the dripping water. A bin would be placed on the bottom of the project while holes on the bottom of the garden that has a form of screening only allowing water to seep through will be placed. Similar to how commercial plant pots have holes on the side for water to drain through. This allows for the bin be the only item that needs to be removed for water cleanup. Pulling out the bin and dumping it out would be all that is needed for cleanup. Creating a bin that fits underneath the garden, sits within the wall and is easy to move would be difficult.

3.8 Sloped Final Water level

A sloped final level on the garden funneling the water to one corner of the structure. Also adding a valve at the end where the water is located allows for easy drainage of water by turning the valve. This level can be made by having a piece of sloped material be installed at the final level. A valve can also be easily installed into the structure by drilling a hole and installing the valve. This allows for a bucket to hold and toss the water out. No movement of the garden needed.

3.9 Sloped Small Bin

A sloped final level that funnels the water into a bin. The final level of the garden will have a sloped material to funnel the water into one side of the garden. The one side collecting the water of the garden will have a bin. The bin will be removable which allows easy disposing of the water. This allows for easy movement and no need for a bucket but if not consistently removed may get overfilled and cause issues when removing.

3.10 Gravel Drainage

The second to last layer of the garden may be filled with gravel allowing for only water to seep through into the drainage system keeping the soil and plants above them having. Filter fabric will be used to separate the two levels. The gravel looks nice and may be pleasing to kids. However, will increase the weight of the total garden significantly.

3.11 Sand Drainage

The second to last layer of the garden may be filled with sand allowing the water to seep through overtime. Holding the plant and soil above it separated by filter fabric. The sand will add significant weight to the garden.

3.12 Baffled Box

The Baffled Box alternative solution would be to create a Plexiglas container fitted to the dimensions of the entire length, but with a single quarter-inch thick baffle made of acrylic in the middle to serve as a support for the entire structure so that it won't bend or wobble under pressure. There will be empty space on the top to serve as space for watering and maybe a lighting system. There will be a buffer between the top edge and the soil to make sure that water does not spill over and keeps the soil in properly. The soil layer would be around ten inches give or take to make sure there is plenty of room for crops to grow annually. A rock/sand layer can be installed underneath the soil to help in draining the water down to the drainage system as well as provide a bit more aesthetic to the project, but it will add a lot of additional weight to the project. The drainage system installed can be a slope created to lead the wastewater into a corner of the box where a valve or plug can empty out the water.

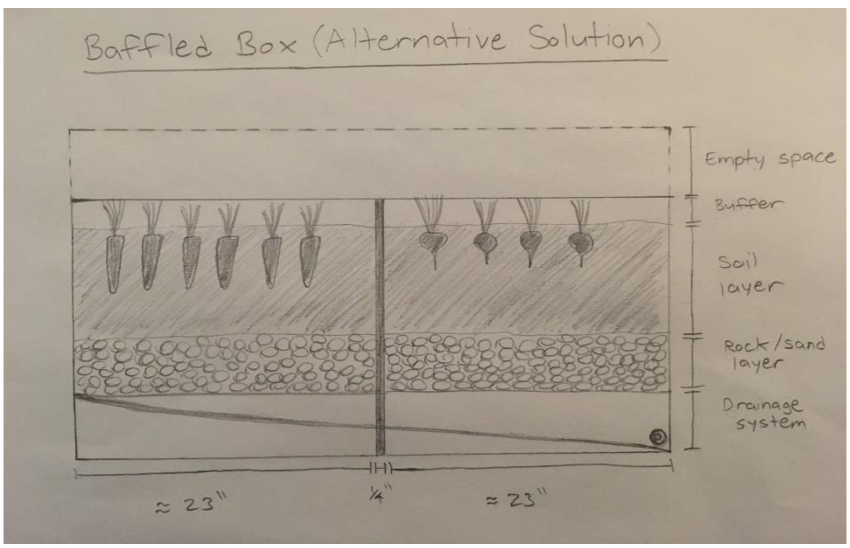


Figure 5:Baffled Box (Alternative solution drawing by Jonathan Lee)

3.13 Filled In

In the Filled In solution, a good portion of the available space for the wall cutout garden will be filled in with filler like polystyrene boxes so that we don't have to worry about fitting the entire wall cutout garden into the given length. This solution will be a lot cheaper due to the reduced amount of materials we will need for the wall cutout garden itself. The length of the actual container should be at least 23 inches because having a height larger than the length can make the wall cutout garden easier to topple over. We will most likely have a much longer length so that we can fit a good number of crops in the wall cutout garden. The drainage system can be either be a valve or bin for emptying the water. The option for using a bin will likely require a funnel so that the wastewater can all collect into the removable container.

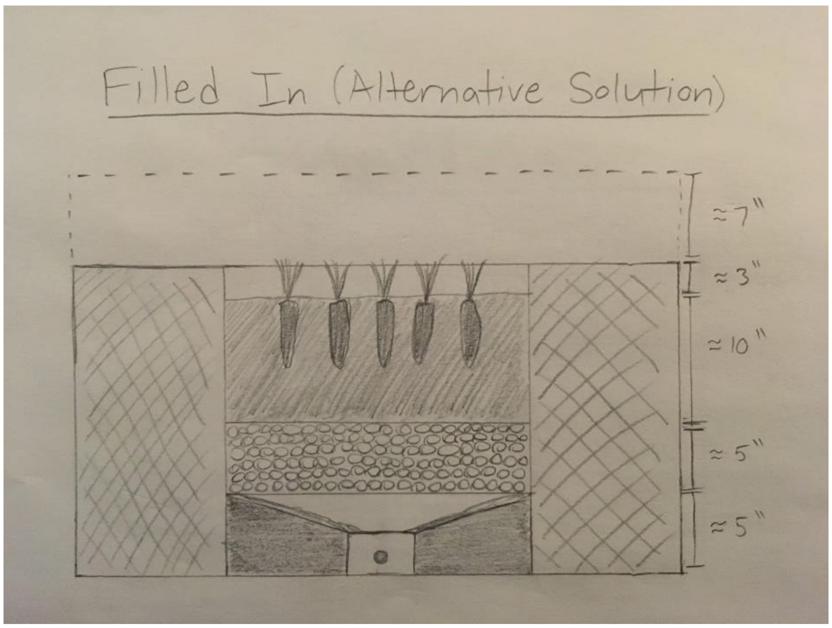


Figure 6: Filled In (Alternative solution drawing by Jonathan Lee)

4 Decision Phase

4.1 Introduction

The decision phase evaluates all alternative solutions from section 3. The Delphi method was used to select a single solution based on criteria from section 2. This section discussed the criteria used, and elaborates on the reasoning behind the selections.

4.2 Criteria Definition

The following definitions of each criteria from Section 2 will be used to justify and compare each alternative solution for the decision process. These definitions are:

Aesthetics: The design's level of cleanliness and appeal to middle school students.

Cost: The design's level of cost based on how expensive it is. The model must have an overall cost equal to or below $400 as stated in Section 2.

Durability: The design's ability to be able to withstand any accidents and abuse caused by middle school students, whether it be from being dropped or bumped into. The model must be able to keep in the soil, water, and crops.

Environmental Impact: The design's level of environmental impact from its functionality and the materials it is made of. The model must be made from at least 25% reused or reusable materials.

Functionality: The design's level of functionality and how well it can grow crops. The model must be able to grow root crops without any fertilizer.

Maintenance: The design's level of maintenance needed to keep its functionality and durability. The model must require occasional draining for only a few days per week.

Portability: The design's level of weight based on how heavy it is. The model must weigh under 30 lbs.

Safety: The design's level of safety for any sort of use. The model must be safe enough for anyone to use under normal conditions.

4.3 Solutions

Based on the alternatives discussed in section 3, the following alternative solutions were considered during the decision phase:

- The Aquarium
- Baffled Box
- Two Separated Wood Boxes
- Filled In
- Heavy Duty
- Lots of Soil
- Wood-Plastic Composite

4.4 Decision Process

The final decision is based off the Delphi matrix analysis. The Delphi matrix is used by assigning weights on a scale of 1-10 based on importance to the project to each of the criteria determined in section 2. These criteria and their weights were determined and voted on beforehand by the team. The seven different project alternatives were then input to the matrix, each team member then rated each alternate on a scale of 1-50 for how well they meet each criterion. This score is multiplied by the criteria weight, giving an overall score for how well an alternative meets each criterion. For each alternative, the scores for each criterion are added up, and the alternative with the highest total score was selected for the project.

4.5 Final Decision Justification

The final design chosen to deliver to the client is the Filled In alternative. This alternative earned the highest score using the Delphi Matrix. The incorporation of wood paneling to fill excess space within the wall cutout allows this alternative to remain mobile. Furthermore, it is expected that this alternative will be aesthetically pleasing and quite durable. Overall, this alternative satisfied all off the identified criteria well, which is why it has been selected.

Figure 7: Delphi Matrix

Criteria		Solutions													
List	Weight	The Aquarium		Baffling Box		Two for One		Filled In		(#5) Heavy Duty		Lots of Soil		Wood-Plastic Composite	
Aesthetics	7	36.25	253.75	28.75	201.25	31.25	218.75	41.25	288.75	33.75	236.25	36.25	253.75	31.25	218.75
Cost	8	36.25	290	26.25	210	24.25	194	38.75	310	21.25	170	31.25	250	30	240
Durability	9	34.5	310.5	37.5	337.5	35	315	36.25	326.25	44.5	400.5	33.75	303.75	33.75	303.75
Enviromental Impact	6	38.75	232.5	30	180	31.25	187.5	36.25	217.5	25	150	31.25	187.5	26.25	157.5
Functionality	10	31.25	312.5	38.75	387.5	41.25	412.5	35	350	35	350	37.5	375	36.25	362.5
Maintance	8	32.5	260	33.75	270	35	280	36.25	290	33.75	270	35	280	33.75	270
Portability	6	35	210	31.25	187.5	45.75	274.5	38.75	232.5	20.5	123	30	180	35	210
Safety	10	38.75	387.5	38.75	387.5	35	350	40.75	407.5	32	320	35	350	38.75	387.5
Totals			2256.75		2161.25		2232.25		2422.5		2019.75		2180		2150

5 Specification

5.1 Introduction

The Specification phase of the document consists of a description of the team's solution to the clients problem, chosen in the decision process. Included are a table of costs, breaking down the construction costs, cost of team's hours of labors, and the future maintenance costs. The different prototypes created and tested are also shown and discussed. Additionally, instructions on using the project and the various implementations are included. The conclusion includes a discussion on the result of the construction and delivery.

5.2 Description of Solution

Our final product is an improved and modified version of the Filled In alternative solution which had the highest score in our Delphi chart decision process in Section 4. The model will incorporate an external wooden frame that will hold the entire structure together. A plexiglass sheet of 0.22” thickness will be placed on each side. The length of the planter will be 30 inches long, and the height will be 23 inches high. The width/thickness of the model will be six inches and will require a 30” x 3.2” x 1” inch block to fill in the gap at the base of the cutout, which will allow the structure to sit on a level base.

The design of our final Filled In solution will have a sloped water sewage system with perforations at the end of the slope for water to fall through. Underneath it will be an approximately 6.5 x 3 x 5 inch separate container to catch the wastewater.

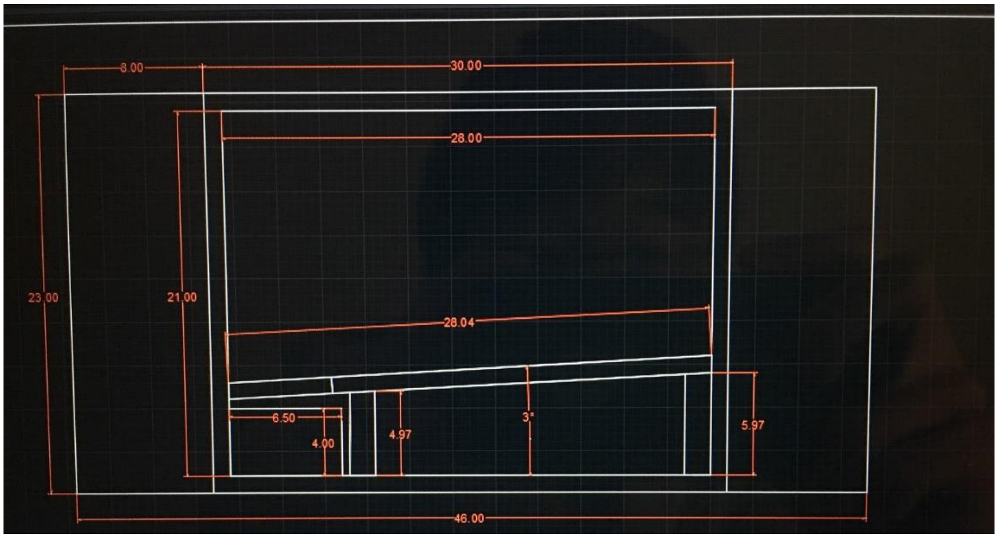
The final design will feature a cabinet beneath the main structure to allow for easy disposal of excess drainage and for storage of necessary materials. Materials such as spare soil, plant nutrients, and a watering container may be stored in this cabinet.

Wood shelves will border each side of the main structure to fill the remainder of the cutout. On the sides of plexiglass sheets there will be two rectangular prisms that will be hollow which are approximately 8 x 6 x 20 inches. The shelves will used for storage and aesthetics. The user will be able to store planter equipment such as shovels and watering cans, or for educational material.

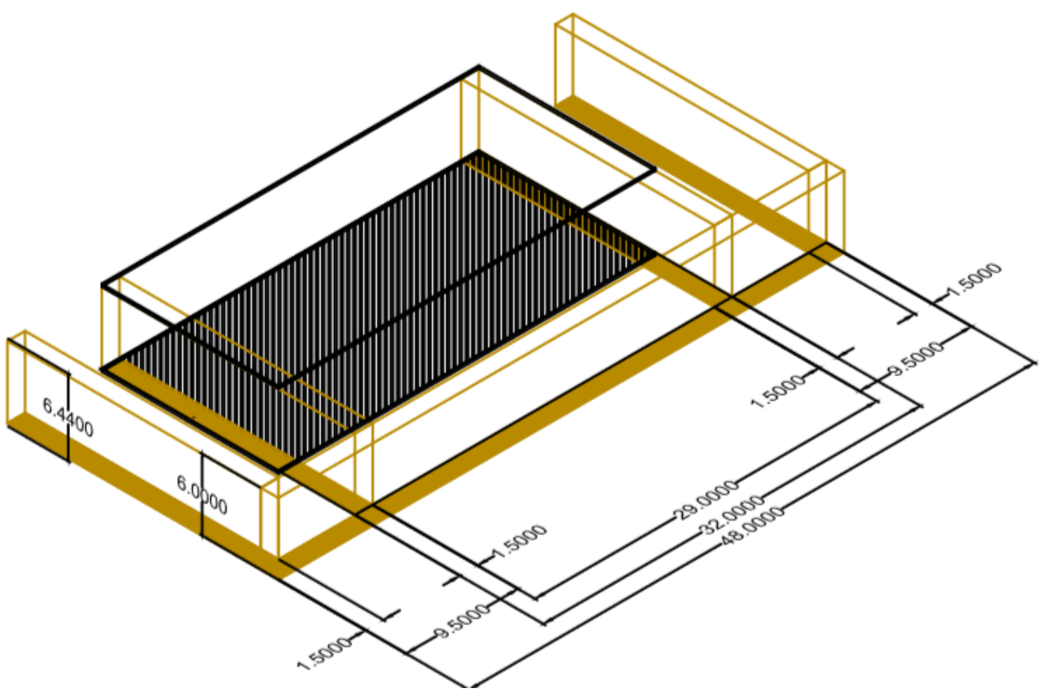
The four images below show the final design and (CAD) drawings of elements of the final design:

Figure 8: Final Filled In Alternative Product

CAD Drawing 1 of the main structure.



CAD Drawing 2 of the wall cutout.



5.3 Prototyping

Simple prototypes were constructed to demonstrate the shape and structure of the design. Prototypes were used to develop ideas about the three-dimensional arrangement of the drainage structure as well as to assess the lateral loading capacity of 0.11" thick plexiglass. These prototypes allowed the team to make decisions regarding the size of the viewing window. From the prototypes, the team learned that 0.11" plexiglass would be too thin to accommodate soil loading, and that a narrower viewing window would result in less lateral flex of plexiglass. Images of the prototypes used are shown below.

Figure 9: Prototype 1: Drainage Visualization

Figure 10: Prototype 2: Lateral Loading of Plexiglass

5.4 Costs

5.4.1 Design Cost (hours)

The design cost is the total number of hours the team has put into each phase of the engineering process. The figure below presents a visual representation of how the teams hours were spent.

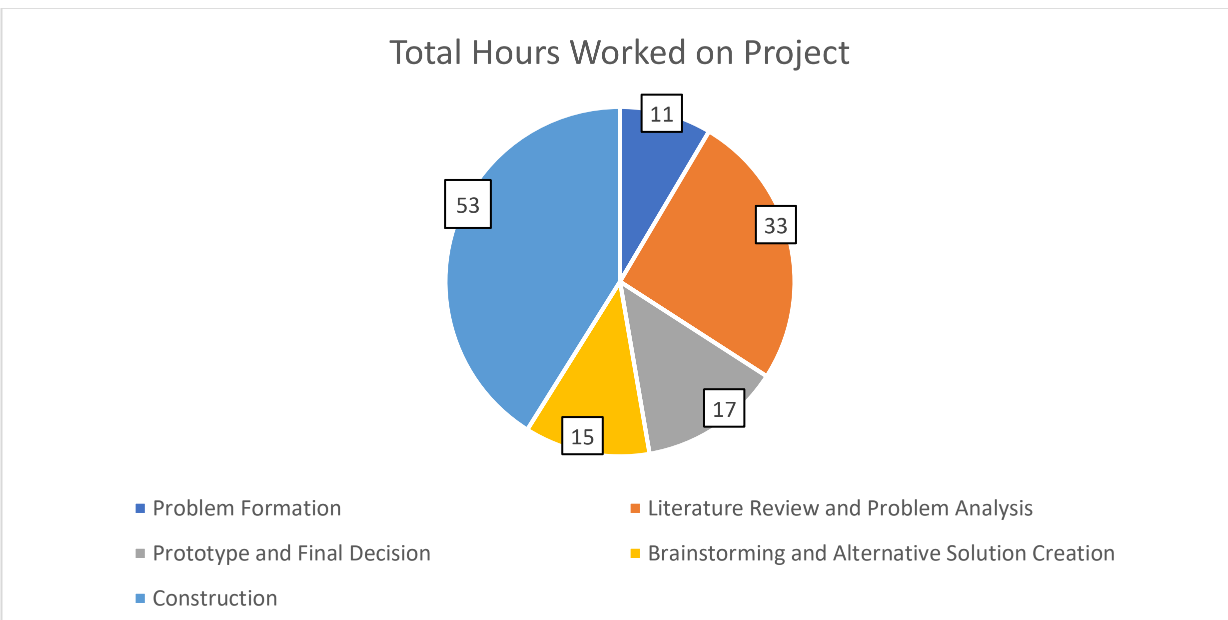


Figure 11:Breakdown of Total Hours Worked on Project

5.4.2 Implementation Cost ($)

The total amount spent on the construction of this project are detailed here.

Figure 12: Cost of Materials

Item	Purpose	Retail Cost	Our Cost

0.11” Prototype Plexiglass	Prototyping	$28.99	Donated
2 Sheets of 0.22” Plexiglass	Windows	$119.98	$50.42
Red and Yellow Spraypaint	Prototyping	$9.18	Donated
Two Red Cedar Planks 20’x1’x1.5” thick	Framing	$64.40	Donated
Two Red Cedar Planks 12’x7”x0.5” thick	Shelving	$43.15	$43.15
Sealant	Waterproofing Connections	$5.99	Donated
Screws	Connections	$6.10	Donated
1/2” Countersink	Making heads of screws flush with plexiglass.	$9.89	Donated
Hinges	Cabinet Connections	$5.99	Donated
Totals		$309.66	$109.56

5.4.3 Maintenance Cost

Over the lifetime of the wall cutout garden, costs will incur to ensure optimal effectiveness and aesthetics of the product. The cost of maintaining this project will be quite low. The soil will need to be replaced every couple of planting season. The desired seeds or seedlings will also need to be purchased when a new crop is desired. Nutrients may also be required depending on plant success. Annual cost of maintenance is estimated at $15 per year.

5.5 Instructions for Implementation and Use

5.5.1 Instructions for Implementation

1. The project will be mounted into the wall cutout of the classroom with screws into the beams on each side.

2. It is recommended that the user check and make sure the cutout garden is mounted securely after every accidental bump and after every watering session.

2. The user will determine crop varieties to be grown and will plant the crops in the soil Seeds or starts could be grown, but starts are recommended for a higher likelihood of success.

5.5.2 Instructions for Use

1. There will be limited physical use of the project, users will generally just observe. It is recommended that the cutout garden be moved as little as possible to minimize chance of accidental damage.

2. Regular watering will be necessary. The watering interval will be determined by soil moisture. It is recommended that the user stick their finger into the soil every two days, and when the soil is dry to the depth of their finger, watering will be required.

3. Seeds or starts will need to be planted after a previous generation dies.

4. The topsoil will may to be replaced, after a 2-3 growing seasons. The user may choose to get the soil tested, in which case, soil amendments may be added to ensure an optimal environment for plant growth.

5.6 Results

The final product proved to be successful in meeting the established criteria from a design perspective. The cutout garden matches the dimensions of the wall cutout, and provides an aesthetically appealing theme. The addition of the shelves on each side of the viewing window adds both practical and aesthetic value to the product. In the future, an addition of an integrated lighting system may be considered to enhance the growing environment. Overall, the team was pleased with the product that was delivered to the client.

Work Cited

"ANATOMY OF A CASTER." (2019). *Casterconnection.com*, <https://casterconnection.com/selecting-right-caster/anatomy-caster/> (Feb. 25, 2019).

"Gate Latch Types - 360 Yardware." (2019). *360 Yardware*, <https://360yardware.com/gate-latch-information-series/gate-latch-types/> (Feb. 25, 2019).

"Hydroponic Systems 101 | Learn The Basics of Hydroponics." (2019). Fullbloomhydroponics.net, <https://www.fullbloomhydroponics.net/hydroponic-systems-101/> (Feb. 25, 2019).

“Inertia and Mass.” (1996). The Physics Classroom, <https://www.physicsclassroom.com/class/newtlaws/Lesson-1/Inertia-and-Mass> (Feb. 25, 2019).

“rollability | Definition of rollability in English by Oxford Dictionaries.” (n.d.). Oxford Dictionaries | English,

“The Importance of Material Hardness for PennCoat's Applications.” (2017). Penncoat Inc, <http://www.penncoatinc.com/materialhardness/> (Feb. 25, 2019).

“What is a Durometer?” (n.d.). What is a Durometer?, <http://ptc1.com/what_is_durometer.htm> (Feb. 25, 2019).

Anderson, R. (2004). Light for Plant Growth in the Classroom. *University of Kentucky Cooperative Extension.* < http://www.uky.edu/hort/sites/www.uky.edu.hort/files/documents/lights.pdf> February 24, 2019.

Baldwin, B.G., Goldman, D.H., Keil, D.J., Patterson, R., Roatti, T.J., and Wiken, D.H. (2012). “The Jepson Manual: Vascular Plants of California.” *University of California Press, Berkeley*.

Daniels, C. (2015). “Vegetables: Growing Radishes in Home Gardens.” *University of Washington Extension*. Publication number FS127E. <http://pubs.wsu.edu>. February 24, 2019.

DerDames, P., DerDames, P. and profile, V. (2019). *Size and Hardness Matters...in Roller Derby Equipment 101*. [online] Blog.prisoncityderbydames.com. Available at: http://blog.prisoncityderbydames.com/2011/05/size-and-hardness-mattersin-roller.html [Accessed 25 Feb. 2019].

Equipment, D. (2019). "Caster Combinations for Trucks". *Douglas Equipment - Industrial Material Handling Equipment*, <https://www.douglasequipment.com/casters-1/caster-combinations-for-trucks/> (Feb. 25, 2019).

Equipment, D. (2019). "Do I Need Rigid or Swivel Wheel Casters? - Douglas Equipment". *Douglas Equipment - Industrial Material Handling Equipment*, <https://www.douglasequipment.com/casters-1/need-rigid-swivel-wheel-casters/> (Feb. 25, 2019).

Grannan, K. (2016). "Hardware 101: Gate Latches - Gardenista". *Gardenista*, <https://www.gardenista.com/posts/hardware-101-gate-latches-style-guide/> (Feb. 25, 2019).

Guy, C. (2016). *Hard Rubber or Soft Rubber? | The Caster Guy*. [online] The Caster Guy. Available at: https://thecasterguy.com/hard-rubber-or-soft-rubber/ [Accessed 25 Feb. 2019].

Holzner, S. (2016). Physics I for dummies. For Dummies, Hoboken, NJ.

kaplan, i. (2019). "US20170015139A1 - Wheel assembly with rolling and swiveling capability - Google Patents". *Patents.google.com*, <https://patents.google.com/patent/US20170015139A1/en> (Feb. 25, 2019).

Lerner, B. (2012). “Onions and Their Relatives.” *Purdue Extension Publication*. Publication number HO-67-W. < https://www.purdue.edu/hla/sites/yardandgarden/extpub/onions-and-their-relatives/> February 24, 2019.

McCormack, J. (2014). “Bean Seed Production.” *Organic Seed production Manuals*. < www.saving ourseeds.org/publications.html> February 24, 2019.

Mills, T., and Dunn, B. (2016). “LED Grow Lights for Plant Production.” *Oklahoma State University Cooperative Extension Publication.* HLA-6450-4. < http://pods.dasnr.okstate.edu/docushare/dsweb/ Get/Document-10413/HLA-6450web.pdf> February 25, 2019.

Oxford Dictionaries, <https://en.oxforddictionaries.com/definition/rollability> (Feb. 25, 2019).

Pennisi, B. (2017). “Growing Indoor Plants with Success.” *University of Georgia Publications*. Bulletin 1318. <extension.uga.edu/publications> February 24, 2019.

Relf, D., McDaniel, A., and Freeborn, J. (2015). *Virginia Cooperative Extension*. 426-402. <www.ext.vt.edu> February 24, 2019.

Sellmer, J., Nuss, R., and Sanford, D. (2017). “Soil Management in Home Gardens and Landscapes.” *Penn. State Extension Publications Distribution Center*. Publication number UJ234. <extension.psu.edu>. February 24, 2019.

Titizian, M. (2015). “Shake? . . . Rattle? . . . or Roll! The Importance of Choosing the Right Caster.” Laboratory Equipment, <https://www.laboratoryequipment.com/article/2005/02/shake-rattle-or-roll-importance-choosing-right-caster> (Feb. 25, 2019).

Toner, R. (2011). “Calculating Commercial Vehicle Weight Distribution & Payload Made Easy.” Green Fleet - Work Truck Online, <https://www.worktruckonline.com/147868/calculating-commercial-vehicle-weight-distribution-payload-made-easy> (Feb. 25, 2019).

Trinklein, D (2002). “Lighting Indoor Plants.” *University of Missouri-Colombia Extension Publication*. Publication number G 6515. < https://extension2.missouri.edu/g6515> February 24, 2019.

World Carrot Museum. (2006) “In Depth Guide to Carrot Cultivation.” < http://www.carrotmuseum. co.uk/cultivation2.html> February 24, 2019.

Zandstra, B., and Warncke, D. (1989). “Radish, Rutabaga, Turnip.” *Michigan State University Cooperative Extension Service*. Bulletin E-2207. < https://www.canr.msu.edu/outreach/>. February 25, 2019.

Gewertz, C. (2015, September 30). The Common Core Explained. *Education Week*. Retrieved Month Day, Year from < http://www.edweek.org/ew/issues/common-core-state-standards/>. February 27,2019

Lynch, Matthew. (19 Oct. 2017) "8 Teaching Techniques for Students With Learning Disabilities." *Education Week - Rules for Engagement* <http://blogs.edweek.org/edweek/education_futures/2016/07/8_teaching_techniques_for_students_with_learning_disabilities.html./>. February 27, 2019

"What Is Autism?" *Autism Speaks*, www.autismspeaks.org/what-autism. February 27, 2019

Team, Understood. "Understanding Special Education." *Understood.org*, <www.understood.org/en/school-learning/special-services/special-education-basics/understanding-special-education.> February 27, 2019

Henriksen, Danah. "Full STEAM Ahead: Creativity in Excellent STEM Teaching Practices." *Scholarship @ Claremont*, <scholarship.claremont.edu/steam/vol1/iss2/15/> February 27, 2019

Arkema Group · Altuglas International (2006). "Plexiglas® general information and physical properties." Plexiglas® by Arkema Group. <https://www.plexiglas.com/export/sites/plexiglas/.content/medias/downloads/sheet-docs/plexiglas-general-information-and-physical-properties.pdf> (Feb. 25, 2019).

GLASSCON GmbH (2015). "8 Common Glass Types – Properties, Applications & Potential" GLASSCON GmbH. <https://www.glasscon.com/blog/8-common-glass-types-properties-applications-potential> (Feb. 25, 2019).

Harris, R. (2018). "Is It Safe to Use Styrofoam in Planters for Vegetables?" SFGate.com. <https://homeguides.sfgate.com/safe-use-styrofoam-planters-vegetables-90628.html> (Feb. 25, 2019).

Josey, B. (1997). "Glass for buildings – is it crystal-clear?" International Journal of Building Pathology and Adaptation; Bingley. <https://search-proquest-com.ezproxy.humboldt.edu/docview/216594620/48A42C681F9F4F4APQ/5?accountid=11532> (Feb. 25, 2019).

Kaseem, M., Hamad, K., Deri, F., and Gun, Y. (2015). "Material properties of polyethylene/wood composites: A review of recent works." Polymer Science Series A - Springer. <https://link.springer.com/article/10.1134/S0965545X15070068> (Feb. 25, 2019).

King, S. and Chen, X. (2015). "US10201909B2 - Treated wood material." Google Patents. <https://patents.google.com/patent/US10201909B2/en> (Feb. 24, 2019).

Mecadi GmbH (2001). "Permeation & Polymers." Mecadi GmbH. <https://www.mecadi.com/en/encyclopedia> (Feb. 25, 2019).

The Aquarium Wiki (2011). "Acrylic" The Aquarium Wiki. <https://www.theaquariumwiki.com/wiki/Acrylic> (Feb. 24, 2019).

Woodford, C. (2018). "Wood." Explain that Stuff. <https://www.explainthatstuff.com/wood.html> (Feb. 24, 2019)

Writing, A. (2017). “Physical Properties of Styrofoam” Sciencing.com. <https://sciencing.com/physical-properties-styrofoam-6141481.html> (Feb. 24, 2019) . Alternative Solutions