SANTA CLARA UNIVERSITY
Department of General Engineering

I HEREBY RECOMMEND THAT THE THESIS PREPARED
UNDER MY SUPERVISION BY

Alexander Kravtsov, Walker Battey

ENTITLED

DYNAMIC SOLAR SHADING

BE ACCEPTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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DYNAMIC SHADING SYSTEM

By

Alexander Kravtsov, Walker Battey

SENIOR DESIGN PROJECT REPORT

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Dynamic Shading System

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ABSTRACT

Long exposure to UV-light radiation can lead to accelerated skin aging and skin cancer. Children are the most susceptible group to the dangers of high UV radiation because of their sensitive skin. Solar shading can provide the staff and clients of Kids on Campus with a way to prevent over-exposure to UV-light radiation by replacing the existing shading structure with a structure that offers significantly better protection from harmful rays. This new structure is also cost-effective, sustainable, and automated. By using a light calibrating sensor that calculates the UV index, we created a dynamic shading system to control and reduce dangerous UV-light in a given space. A permanent pergola structure was built on the Kids on Campus playground that accommodates a dynamic shading mechanism and operates according to light sensor readings. The result was an 84% UV light reduction under the pergola, making the space safer for the children and staff. To improve the dynamic shading system, a closed loop-feedback system can be implemented to operate each roller separately based on solar geometry. Such enhancement can improve power efficiency and transform space to make it even more practical.

Keywords: Solar shading, UV reduction, space optimization

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

Section 1 - Introduction

This paper details our Senior Design Capstone Project, undertaken during the 2020-2021 academic year. The first section of this thesis describes the inspiration for this project, beginning with an explanation of the main problem that the project was designed to solve: overexposure to UV radiation. Current technology that is commonly used in similar fields is then discussed to provide context for our motivation and client expectations.

1.1 Background

This subsection dives into the background of the project. It starts with a brief description of UV radiation and its impact on humans and then continues with current solutions for issues related to solar radiation.

1.1.1 UV Radiation

Ultraviolet radiation is a form of non-ionizing radiation that reaches the Earth's surface from the Sun. Despite the benefits of UV-light, such as the creation of vitamin D, there are also various harmful aspects to radiation which include health risks. There are two main wave types of ultraviolet light that reach the surface of our planet. UV-A light, which is almost 90% of UV radiation, is not absorbed by the ozone layer and has a relatively longer wavelength which allows it to penetrate deep into the skin, past the dermis layer. Overexposure to this type of light is associated with aging and skin cancer. UV-B light has a slightly shorter wavelength and is mostly absorbed by the ozone layer. This light is less harmful as it doesn't penetrate the skin deep enough to cause as much damage.

Extended exposure to UV-A radiation can adversely affect a person's immune system. The way people behave outdoors, during daylight is the main source of the rise in skin cancer rates in recent history. Children are the most susceptible group due to their skin being thinner and more sensitive. Estimates show that by the age of 18, people have already absorbed up to 80 percent of their lifetime exposure to ultraviolet light [1]. The World Health Organization (WHO) has developed the UV index (see Figure 1), which is a measure of intensity of UV radiation, to help raise awareness about exposure to harmful solar radiation [2]. The five main tiers are divided on the scale from 0 to 11+ from "Low" at 1 and 2, to "High" at 6 and 7, and to "Extreme" at 11 and higher. Readings above 3 are already considered harmful warranting the reduction of further exposure to direct sunlight. In Northern California, the UV index climatological mean for May reads at 6, meaning the risk of harm is at high and outdoor activities should be minimized during the hours between 10 a.m. and 4 p.m. [1].

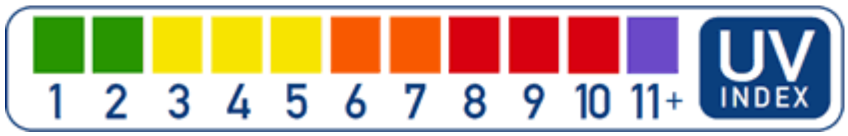


Figure 1. UV index scale [1]

1.1.2 Solar Shading

Solar shading technology is used in civil industries in order to control the amount of sunlight that a building receives. Using solar geometry factors, such as the sun's altitude and azimuth, various blinds systems can be manipulated to create a solar shading mechanism [3]. In warmer climates, where solar radiation is higher, solar shading can be implemented to reduce cooling energy consumption. It can also be used in colder climates to improve passive heating. Successful solar shading can reduce energy consumption by up to 15% [4]. Solar shading is sustainable, maximizes space usage, and improves thermal conditions in a given area.

In outdoor settings, solar shading can be used to create more usable space during daylight hours when UV light is most harmful. While it doesn't eradicate UV radiation completely, being in the shade can significantly reduce ultraviolet exposure [5]. If shading is automated, it can result in a dynamic space that can be manipulated to facilitate zones that are safe for people to occupy during high UV exposure times. This promotes a healthier outdoor lifestyle by expanding the number of UV-safe hours of utility of a given outdoor space,

1.2 Motivation and Significance

Our project was designed for our project partner, Kids on Campus, detailed in Section 1.2.1. Through these subsections the reader will learn about the project's inspiration and reasoning behind the group's goals and objectives, as well as its proposed impacts.

1.2.1 Client

Our client is the daycare center, Kids on Campus, located across the street from Santa Clara University's Benson Center and the Graham Dormitory. The Kids on Campus Education Center has two programs, the first is the infant-toddler program which educates children between the ages of 6 weeks and 2.5 years. The second program at Kids on Campus is the preschool program which educates children between the ages of 2.5 and 6 years.

Our primary objective was to reduce the amount of UV exposure to these children throughout the day so that they might be able to optimize the use of their outdoor space. The preschool operates between the hours of 8 am and 5 pm, therefore the focus of our project needed to concentrate on reducing harmful UV light during these hours of operation. During these hours, the children are at the most risk for overexposure to UV radiation and we aim to provide a greater area that reduces the UV radiation exposure that the children experience, allowing both the children and staff to work outside more often and with larger groups.

The original condition of the outdoor space was mostly exposed to direct sunlight. To shade the sand playground a temporary plastic structure was placed (see Figure 2). This solution was not only weak and unsafe for kids but also too costly to operate. A yearly maintenance fee of up to $200 was causing Kids on Campus unnecessary spending and preventing them from utilizing their money on other learning activities. Other than this, the structure itself was very fragile as it was not fixed properly in the ground and instead resembled a tent secured with stakes.

Figure 2. Original structure at Kids on Campus

1.2.2 End User

As our client and main point of contact, Deborah Gray, was only one small segment of what we considered to be our end user group. We needed to consider the students and the staff who all would be impacted by our project.

As we began to consider the main demographic that our project would impact, we also began to understand that much of our project needed to be modified in order to fulfill project objectives and success metrics (see Section 2.3). Many of these considerations and improvements were a result of risk identification and mitigation (see Section 2.5) in acknowledgement of our wider definition of who the end users will be the children & staff. This acknowledgement came about as we began to recognize the impact on the health of the children that our structure and system would have.

Through our interview we were able to establish overall conditions and ways that the staff and children were using the playground space. The primary concern that the staff had was the constant visibility of children to ensure their safety. From our client we realized that the children require as much space as possible to accommodate their active spirit. Their average height had to be taken in consideration as we wanted to provide the best user-experience for both children and the staff. Our client told us that most kids are between 3 and 4 feet tall.

1.2.3 Overall Impact

The purpose of this project was to help our client, Kids on Campus, to maximize their outdoor space by creating a safe and cost-effective shaded area. Clear communication with our client, Deborah Gray, allowed us to create success metrics to better evaluate our goals for the project.

Achieving UV reduction was the main criteria to evaluate our project’s success. Another important factor in the project's success was the overall safety of the structure and system. Building protocols were carefully considered to maximize this safety. The stationary structure was treated with solutions to guard against any damage from the elements. The dynamic solar shading mechanism was also treated to withstand outdoor conditions. Collaboration with our client to review concerns helped us identify risks so they could be mitigated. Those specifics will be discussed in more detail in Section 2.4.

We chose green energy sources because we were dedicated to sustainable technologies while avoiding any ecological impact. All subsystems of this project were carefully analyzed for their ecological imprints, as we did not want to negatively impact any ecosystems. Our goal was to create a safe, sustainable, long-term solution to minimize future operation costs. This could best be achieved through the lens of sustainability. We are planning to facilitate an educational opportunity for children regarding their exposure to green energy sources.

Section 2 - System Architecture

This section discusses the overall structure and organization of the project, beginning with the System Overview (Section 2.1). Subsystems are followed in subsequent sections, beginning with Structure in Section 3, continuing with Power in Sections 4, and wrapping up with Electronics in Section 5. Additional information regarding project management and the actual design process is provided in Section 2.3.

2.1 System Overview

This subsection introduces the overall system architecture and provides its visualization in Figure 3. The system's architecture also includes five main subsystems (also illustrated in Figure 3**)** and include structure, power, actuation, computer, and sensors. This architecture was used to optimize the program management aspect of this project and to help visualize the required tasks for each subsystem.

The structural subsystem includes the pergola and shading fabric that were built to replace the old structure shown in Figure 2. This system represents the stationary side of the project that is designed to be maintained as little as possible. Details regarding the structure subsystem are available in Section 3.

The power subsystem represents the electrical parts of the project and includes the solar power for all main circuits that are used in this design. Due to a number of power dissipative elements in the system, Power is a subsystem that causes many potential risks which are discussed later in Section 2.5 and tied back to success metrics of Section 2.3. Details for the electrical subsystem are available in Section 4.

Actuation, computer, and sensor subsystems are all merged under the Electronics section (see Section 5). These subsystems represent the solar shading mechanism and are essential to the project. Actuation includes mechanical and user-interface sides of the project that drive the system and engage with the client and users. Computer and sensor subsystems are the brains of this system and serve as input and decision-making components of the project. Operation principle of the electronics is described later in Section 6, followed by the final shading mechanism in Section 7.

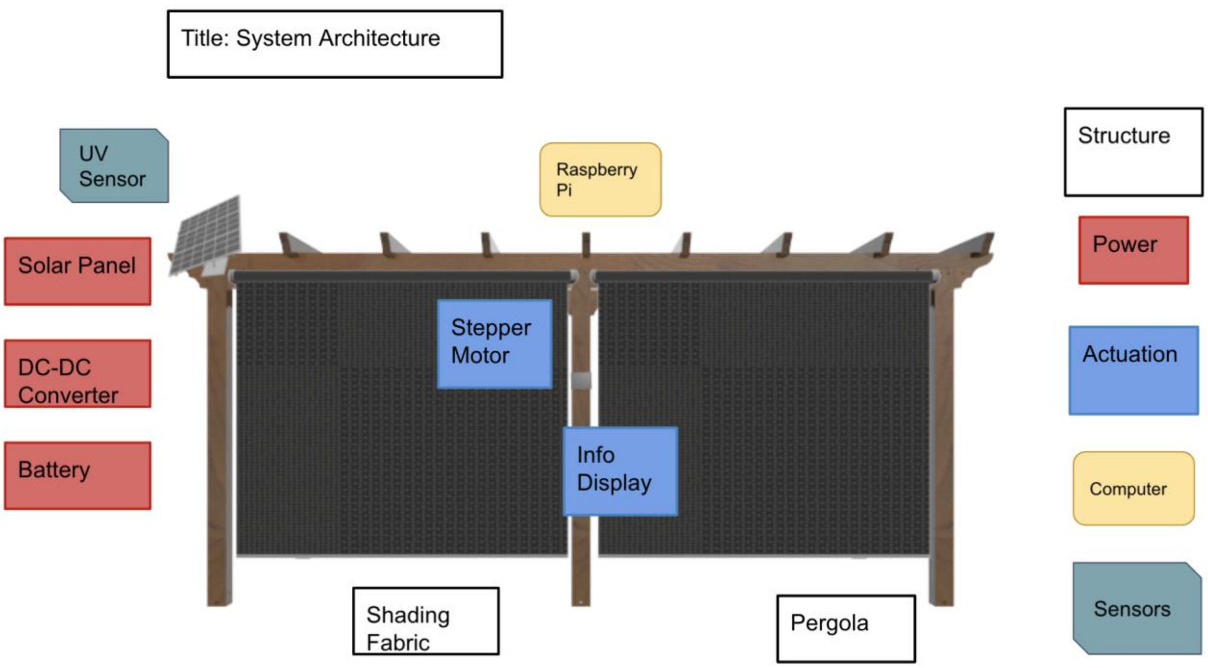


Figure 3. System architecture

2.2 Program Management

The key to this project was a well-managed framework for scheduling and completing tasks. The two main tools used for this were Trello and a Gantt chart (found in Appendix B). The former helped us communicate our findings and visualize the research in one place that all members would have access to. The latter was used to divide tasks throughout the quarter. Successful categorization of each subsystem helped establish clear roles for team members and allowed for a better understanding of the order in which tasks were to be completed. Color coordinating each subsystem by project partner helped the overall organization and communication between project members and the faculty advisor. Team roles were divided according to each team member's strength. The construction of the project was a joint effort as it required multiple people to complete safely. Programming and the hardware details of the project were divided equally based on the partner's skills and preferences.

2.3 Success Metrics

From the very beginning of our communication with the client expectations were established. These hopes from the project were then discussed by our team members and reorganized into success metrics that were considered at every stage of the design process.

After the system architecture was created it became clear that each subsystem will have its own impact on the project. In order to coordinate our design process, project success metrics were corresponded to each separate system and are listed in Table 1 below. From this we were able to establish risks associated with each system and discuss the findings later in Section 2.5.

Table 1. Success Metrics and Corresponding Systems

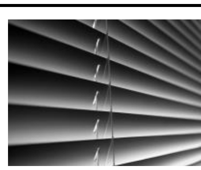
Success Metrics	Systems Corresponding to Each Metric
Reduction of UV Radiation	**Actuation** **Sensor**
Safety factor of structure and system	**Structure** **Power** **Sensor** **Actuation** **Computer**
Protection of children's **health**	**Structure** **Actuation**
Exposure of children to **sustainable** technologies	**Power** **Actuation**
Facilitation of an educational opportunity regarding **green energy** sources	**Power** **Actuation**
Ecological impact	**Structure** **Power**

2.4 Design Process

This section describes the path our project group took in approaching the final design for the system and shows the current products on the market that demonstrates any feature similar to our project (see Table 2).

When designing the actual mechanism, factors such as the ability to withstand a variety of weather conditions and safety had to be considered. After doing research on different types of shading mechanisms, that can be seen in Table 2, our team created an evaluation matrix to help us determine the most feasible solution [6]. The two main criteria were simplicity of use and sustainability. Our team chose roller shades, as they had a simpler design that would require less variable moving parts that could become a potential hazard. Roller blind mechanisms have one type of motion, translation, that can be easily created using rotational motion of motors.

Table 2. Evaluation of Shading Mechanisms

Shading Type	Image	Type of Motion	Additional Items	Simplicity (out of 10)	Weatherproofness (out of 10)
Roller Shades		Translation	Fabric	9	8
Louvres		Rotation	Slats	6	7
Folding panels		Rotation / translation	Panels	3	6

The original design that was used for the prototype of the shading system was an at-home roller shade system and can be seen in Appendix A**.** It included a pipe approximately ⅔ of an inch in diameter that acted as a roller for the shades. By directly connecting the roller to the motor, the shade was successfully rotated with the shading fabric attached to it. After testing was complete the fabric turned out to be suitable for UV reduction, however it did not fit within the requirements for our project as this is an outdoor structure for which a breathable fabric would be vital. The issue was that under rainy conditions the fabric did not let the water through, which would make operation of the system more complex and less autonomous. Through this design process, there were many lessons learned regarding possible problems with the mechanism. The main one was figuring out the required torque to drive a larger, heavier version of the system with more fabric attached. The next issue that we identified was the need to secure a tighter fit of the fabric to hold the shade taut and in place.

2.5 Risk Analysis/Assessment

This subsection describes the path our project group took in determining the risks associated with our project, the intervention techniques we might apply to the risks and the probability of occurrence associated with each risk.

2.5.1 Risk Identification

In identifying the risks associated with our project, we considered the project site, the client, the end-user and the environment and the ecosystems at the project site. With our client's input, we were able to identify risks including consideration for the holes to be deep enough for the beams so we could bury their concrete supports to avoid the hazard of children running into them.

Many of the risks that we were able to identify during our communications with our project partner were associated with how safely the structure was constructed. We were careful to consider all aspects of the construction process as well as the safety of the completed structure and system and listed all of them in Appendix C under Project Hazard Assessment. Furthermore, as we identified many of those safety concerns it helped us consider how to mitigate future safety concerns that might arise given prolonged exposure to as well as use and abuse by the children.

This allowed us to consider how we might also alter our code to prevent the need for excess interaction with the system that could potentially lead to failure.

2.5.2 Risk Intervention Techniques

To achieve the best possible end product, in the initial stages of the project we brainstormed different ways we could reduce or mitigate the different project risks. Evaluation of risks and ways of mitigating them are listed in Table 3 below. The first, and most important step in doing this was comprehending how a risk could be posed and breaking down that risk to understand its source. This was particularly exemplified by the steps we took to ensure the longevity of the structure. In this specific case, multiple variables were considered. Such variables were the stain we would use one the wood for our structure as we wanted to ensure that the stain would not negatively impact the environment around our structure. Another variable was the type of wood we decided to use as we wanted to ensure that the wood would be able to support the weight of our system as well as last an extended period of time. A third variable we considered was the type of bracket that we needed for our structure and whether or not the bracket we would use could actually withstand the force applied by the system and any other external actor. As we did not want the structure to negatively impact the environment around it and to ensure the longevity of the structure, we made sure to complete enough research into each of the variables to ensure that there would be no negative impact, environmentally or otherwise.

In order to properly intervene, we used the rough outline of risk mitigation techniques to understand the root of each risk posed. For the stain, the wood selection, and bracket selection, our primary concern was the risk of poor longevity. To mitigate this problem, we researched all the available products comparing and contrasting their efficacy. Once we chose a particular product for its resiliency, we needed to then take into consideration any harmful effects it might have toward the users of the system. This thorough approach was particularly important when it came to choosing a type of wood stain. We wanted to make sure there were no residual problems with off-gases in its implementation and application to our project. Table 3 shows the list of risks that we identified, the probability of each risk occurring, and the possible mitigation techniques we might apply to best counter the risks.

Table 3. Risks and Mitigations

Risk	Probability	Mitigate
Stability/Longevity of the Structure	Low	Material Selection Research
Safety of the concrete base	Medium	Statics analysis of a concrete support
Wiring Safety	High	Wiring has protective covering and is not overly conductive
Attachment of DSS	Low	
Not leak-proof	Low	Seal all wiring, proper material selection
Unequal distribution of light on the photoresistor	Low	Grid of photoresistors throughout the structure
Stability/Longevity of the Structure	Low	Material Selection Research
Safety of wiring connections	Medium	Reduce probability by sealing all connections in advance
Safety of the concrete base	Low	Follow instructions and wait required times when pouring concrete
Battery overcharge	Low	Check all connections, from the solar panel to the microcontroller
Shade mechanism stopping mechanism	Medium	Find optimal stopping point and include in the code
Safety of surroundings	Low	Keep safe distance between the testing and people watching
Shipping delay	Medium	Ship in advance, complete other parts of the project if happens
Sickness	High	Reduce chances of being exposed to COVID

Section 3 - Structure

This subsection describes the determination of the final design for our pergola, how we prepared our materials for construction as well as the different construction techniques we implemented in our project.

3.1 Pergola Design

Throughout the preliminary stages of designing the functionality and overall aesthetic of our design, some of our primary concerns were the cost and aesthetic of the structure. Originally, we were hoping to purchase either a prefabricated pergola, or a kit that came with all of the pieces for us to be able to utilize in the design and build our own structure using some of the pieces and joining and installation instructions from the kit. The prefabricated pergolas and pergola kits that we considered came with all of the parts we would need to build the main structure, including the top sail of the pergola. We did not want to purchase a prefabricated pergola or pergola kit that included side shades as we would be applying our actuated shading system to the sides of the pergola. As we continued to look through the prefabricated pergolas and pergola kits online, we found that the prefabricated pergolas and the kits that were frequently purchased by others and fit the general visual profile designated by our client were too costly for the budget given to us for the project.

One of the issues that came about while we were searching for a pre-fab structure was the cost. Most of the prefabricated pergolas required assembly and cost much more than what we had originally thought and accounted for in our project budget. We then consulted with our client and found an alternative solution as we began to realize that the purchase of a prefabricated pergola, or a pergola kit, would result in the loss of over half of our project budget. Instead we decided to purchase a set of pergola securing brackets. This particular kit included eight total brackets, four of which were included to secure each of the legs of the pergola to the ground. Though our pergola was secured to the ground using four separate holes and concrete, we still attached these brackets to help ensure the safety of the structure. The other four brackets were joining brackets that allowed three pieces of wood to be secured together at one point. This kit, however, did not include any of the wood, or the shade that we would need for our structure.

3.2 Preparation

The wood for our structure included four 10 feet and four 12 feet long 4x4 beams we purchased from Home Depot. These had square edges that could potentially pose a risk to the children. Therefore, we rented a table router and a rounded drill bit to remove these sharp edges, creating a softer, rounded edge that would pose much less of a risk to the children. Once we had rounded off all the edges of the pieces we would be using as legs for the structure, we began a two-phase sanding process. The first phase began by using 60 grit sandpaper. The grit of the sandpaper refers to how coarse, or smooth, the sandpaper is. The lower the grit, the coarser the sandpaper will be. With this 60-grit sandpaper, we were able to sand away the larger blemishes and chips in our 4x4's that also posed a risk. Having completed the first phase of sanding, we continued to the second phase with 320 grit sandpaper, which is a very fine grit. This fine of a grit made the wood soft and smooth to the touch to help avoid the risk of causing splinters. The purpose of sanding our wood, however, was not to just get rid of the blemishes and mitigate the risk of splinters, but to also prepare the wood for staining. Sanding wood allows the pores of the wood to open so that it will soak in more stain. A hefty coat of stain would help protect the wood and add to the longevity of the structure.

In order to better protect the wood, and the environment around our structure, we decided to use Copper-Green Brown Wood Preservative. This wood stain greatly increases the longevity of the wood and repels wood-eating insects like termites. We decided to use this wood stain preservative because it was one of a few that also had incredibly low ecological impact. The only risk this preservative poses is to sea-life, obviously not present on the Kids on Campus site. Once sanded, stained, and routed, the next logical step was to build the physical structure.

3.3 Construction

Our first step in construction was to measure and dig four separate holes, into which each of the corner legs of the pergola would be placed to provide safe further structural support for the pergola. From our calculations in Appendix D, we then dug each of the holes 2 feet deep in order to account for the weight of the structure and the structural support needed for the system to be safe.

In digging the holes, we ran into multiple issues. While digging our first hole, we found that about six inches deep into the dirt and grass, there was a very thick mesh tarp that was separating the dirt from a layer of gravel underneath. This mesh was an issue because it was very thick and proved difficult to dig through or to cut out of the way. Once we had cut through enough mesh to continue digging the hole, underneath the mesh was medium sized gravel that, once removed, would be refilled and replaced by the gravel which surrounded the hole, so we needed to support the side walls of the hole as we dug deeper. Once we had made significant progress through the gravel, we encountered the third and final challenge to our dig - a water pipe for the sprinkler system. We did not want our construction to damage the water line or impede the progress of our project. After consulting with the Santa Clara University Facilities Department, we then decided that the best way to proceed was to separate the area where we would be pouring the concrete from the waterline using cardboard so as to not adversely affect the waterline, and still allow SCU Facilities to be able to work with and on the waterline should they need to be able to access that specific area.

Once we had dug our holes deep enough, we then decided to do a rough construction of the structure. We placed all of our pergola legs into the holes with the brackets mounted at the top. Once all four legs were in each of the holes, we then placed all of the arms into their coinciding brackets. By using this method, we were able to decipher which holes needed to be adjusted in order to provide the best possible structural support. Once we had adjusted all of the holes to our and our client's liking, and had ensured that they were plum, we then drilled all of the bolts through the brackets and into the wood pieces in order to secure the structure.

Having drilled the brackets into the wood pieces, and ensured that all the joints were plumb, we then proceeded to secure the legs of the pergola in their respective holes. To do this, we used Quikrete Dry Cement. We poured the mixture into the hole and gradually filled it with the designated amount of water, stirring constantly to ensure that the cement mixture would dry evenly and properly, to provide the structural support required.

Once the concrete had cured, the next step was to fasten the top shade to the pergola as it would be a permanent, non-actuated fixture. Using the carabiners, rope and eye brackets supplied with our shading material, we then fixed our top shade to the arms of the pergola to provide the intermediary shade. Next, we finished the actuated side shades and code to operate the system.

With our actuated shade housing complete, and the motors placed inside the housing unit that we had 3D printed, we then secured the housing to the arm of the pergola. We did this by drilling a bolt through the housing and into the wood, similar to how we secured the metal brackets that connected all of the beams for the structure.

Section 4 - Power

This section describes the choice of energy sources for the system and provides information regarding power consumption of various subsystems. We articulate our testing protocol for the solar panel and the decisions we made regarding the mounting process.

4.1 Solar Panel

One of the main success criteria for the project is a creation of an educational opportunity for children regarding green energy sources. A big part of this criteria lies through exposure to sustainable technologies. Therefore, we decided to use solar energy to power the system we built to protect children from solar radiation. In order to determine the required specifications for the solar panel power consumption all energy dissipating elements needed to be analyzed. There are three main power consuming devices that will be later discussed in Section 5 - Raspberry Pi, 2x high torque stepper motors, information display. Table 4 shows recommended voltage and current supply of different electronic elements and the overall power consumption in Watts-hour, based on a 7-hour operating cycle. As a result, a 100 Watt solar panel was chosen with an additional consideration of excess power for varying weather conditions. The solar panel kit that is used for the project consists of the solar panel and the solar charge controller, which will be later described in Section 5.2.1 of Battery Charging Circuit.

Table 4. Power Consumption of Electronics

Item	**Recommended Voltage Capacity (V)**	**Recommended Current Capacity (A)**
Raspberry Pi 4	5	3.0
2x High-Torque Bipolar Stepper Motor	3-7	3.0
Information Display	5	Supplied by Raspberry Pi
Power Consumption (W)		**45**
Overall Power Consumption (Wh)		**315**
Solar Panel Power Generated (Wh)		**400**

The power output of a solar panel depends on the current and voltage that each photo-voltaic module produces. In order to ensure all electronics can be continuously powered, we had to make an emphasis on the highest attainable current flow to achieve the maximum power. The highest current flow from solar panels is achieved through the most direct exposure to the sun [7]. To find the largest attainable flow of electrons we created a testing protocol which allowed us to visualize our results. The goal was to test the solar panel at different angles throughout different times of the day at various conditions. The testing took place in the end of February and beginning of March, when the sun's elevation angle relative to the ground is lower than in the months of harmful solar radiation. The results are presented in Figure 4 below.

The sun's elevation over the daycare center varies depending on the time of the day. Our goal is to capture the short period of time that the sun is at the highest angle and extract the most power out of solar panels. For example, on May 3rd 2021, when Kids on Campus reopened their doors, the sun's altitude crossed the 40 degree elevation mark at around 9:40 am and then again at 4:30pm. These hours match the working hours of the daycare and allow for enough power to generate to run the system. Through the testing we were able to measure the peak current flow of around 5.2 A at the angles above 45 degrees when the sun's elevation was still low. As the sun rose higher to the middle of the day, the current flow decreased at the higher elevation of the panel. The angle of 45 degrees between the ground and the panel was chosen to be the most efficient for the all day use. At this angle, a 100 W solar panel should optimally generate up to 400 Wh per day which correlates to about 33.4 Ah. The operation principle, which is later described in section 6, tells us that the motors are required to be engaged only once per hour between the hours of 8 am and 5 pm. During a seven-hour work day, there should be a surplus of 85 W of power generated than required to operate the mechanism. The excess power is useful in case weather conditions are poor and less power can be generated.

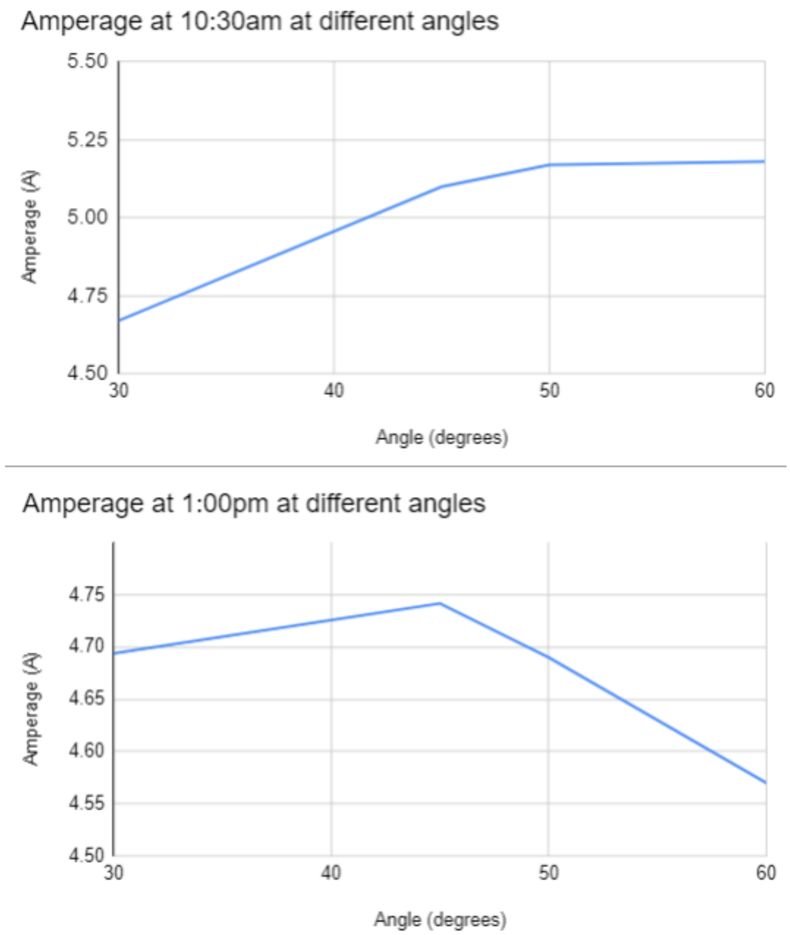


Figure 4. Solar panel testing results

4.2 Battery

The original goal for storing energy was to reduce the need to replace batteries, and therefore reduce the cost of operation. The two main criteria when choosing the battery are a matching electric potential with the solar panel output and its capacity. The solar panel that was chosen for this project works only with 12/24 V batteries, therefore the options were limited to a 12 V power source. A primary concern for the battery was its storage capacity as the exposure of solar panels to the sun varies based on weather conditions and the system implies an everyday use. The final battery choice landed on the 12 V 6800 mAh lithium-ion battery. This battery can withstand the maximum charging current of 6600 mA, which is above the limits of the solar panel output current.

4.3 Wiring

In order to reduce the chance of voltage drop the length of wires has to be considered. The primary concern for the voltage drop is within a battery charging circuit that will be later described in section 5.2.1 as the solar panel output is inconsistent and its current varies. For the cables that came with the solar panel kit, the recommended length is shorter than the length of 12 feet at the current flow of 6 A. With the increase of wire gauge sizes, the resistance of copper wires increases meaning that shorter wires are required to reduce a potential voltage drop. The wires that are used in the project and will be discussed in this thesis are listed below in Table 5.

Table 5. Power Wiring Diagram

Wire Name	**Wire Gauge (AWG)**	**Usage**
Battery Lead	11 AWG	Battery to Solar Charge Controller
Solar Panel Wire	11 AWG	Solar panel wire fixers
Solar Panel Wire Extension	11 AWG	Up to 20’ of extension
DC Power Cable (Female Plug to Bare Wire)	16AWG	Battery to Raspberry Pi
DC Power Cable (Male Plug to Bare Wire)	18AWG	Battery to Solar Charge Controller
Power Cable	16 AWG	Extension for Battery to Raspberry Pi

Section 5 - Electronics

This section dives into the hardware aspect of the project. It starts with the description of the computer subsystem that operates the dynamic shading mechanism. It then examines various circuitries and their key components. The section ends with the user-interface side of the project, the display, and its operation principles.

5.1 Raspberry Pi

In order to operate the shading mechanism a controller had to be chosen. The two main options were Arduino Uno and Raspberry Pi. The latter was chosen for its support of Python and its responsive user-interface in the form of a full operating system. Despite having a larger energy consumption, Raspberry Pi is still a relatively low power consumer. In order to simplify the prototyping process, Raspberry Pi 4 was chosen due to its convenient GPIO connections.

5.2 Circuitry

This project contains two main circuits - battery charging and motor driving circuits. It analyzes the operation principle of each and dives deeper in separate components that make up the hardware of the system. Details on each circuit are available in the following subsections.

5.2.1 Battery Charging Circuit

The solar charge controller that comes with the solar panel kit is a 30 A pulse-width modulation controller, meaning it controls and manipulates the power output to efficiently deliver it to the battery. This reduces the risk of the battery overcharge and ensures the maximum power delivery.

As discussed in section 4.3, in order to ensure the most efficient flow of energy gauge wire sizes have to be considered. The battery connects directly to the solar charge controller using 11 AWG wires that come with the solar panel kit. The 12 V lithium-ion battery that is used in this project comes with two wiring connectors, a female plug that charges the battery and the male plug that discharges it. In order to properly connect the battery to the solar charge controller the 11 AWG wire is soldered to the 3’ 18 AWG DC power cable with the female plug to bare wire connections. This minimizes the risk of a voltage drop as the length of each cable is minimized allowing for an adjacent to the panel battery storage. The end of the other battery wire is then plugged to the 16 AWG DC power cable with the male plug to bare connection that powers the Raspberry Pi. To ensure a proper power supply a 12 V-5 V step down converter is used, which comes with a convenient USB-C cable on the other end of the converter that can directly plug into the Raspberry Pi.

5.2.2 Motor Circuit

The motor circuit used to power motors of the shading mechanism is the main hardware system of the project. There are two main subsystems to the motor circuit, the stepper motors themselves and drivers that run them.

5.2.2.1 Motors

In order to ensure a steady rotation of the roller shades correct motors have to be chosen. Using a torque equation listed below, the required torque was calculated. The distance used in the equation is the diameter of a rotating rod, 1 inch, while the force is the overall weight of the 10' roller with the fabric, approximately 10 lbs. Torque was calculated and converted to N*m to simplify the motor search. The final calculation for the required torque gave us 1.29 N*m of rotational force.

$$\tau = rF\sin(\theta) \qquad \text{(eq. 1)}$$

To provide a smooth and precise rotation bipolar stepper motors were chosen to actuate the shading mechanism. Compared to servos, stepper motors offer a more precise motion at a higher torque. As a result, a high, 1.9 N*m, torque stepper motor was selected, which is suitable for CNC mill applications. The excess torque is needed to provide a flawless operation despite varying weather and wind conditions that could increase the force acting on motors.

Selected motors can operate at voltages ranging from as low as 3.3 V at the current flow of 3.0 A. For this reason, motors are directly connected to the battery pack to ensure enough power is transferred for motors to rotate. At a step angle of 1.8 degrees the motor takes 200 steps per single revolution, providing precise motion that allows for the smallest adjustments.

5.2.2.2 Stepper Motor Driver

To allow the motors to operate correctly they need to be driven with proper actuators that will translate pulse signal into an angular displacement signal. DRV8825 motor drivers were chosen for this project because of their relatively low power consumption yet powerful enough to operate at different step resolutions. Requiring only 3.3 V, sensors get the energy supply directly by the Raspberry Pi using the 3.3 V pin. These drivers feature six different step resolutions that create an even more precise motion. DRV8825 motor drives come with additional heat sinks that are used to prevent these modules from overheating.

Stepper motor drivers connect to two GPIO pins on the Raspberry Pi board to communicate with the computer. Motors are then connected to 2A, 1A, 1B, and 2B, to ensure that each one of the coil phases can be activated. In order to power motors, the battery is connected to the VMOT and GND pins of the driver with a 100 uF capacitor connected between those pins. This is a bypass capacitor that acts as a stabilizer for power and noise reduction and minimizes chances of voltage and load fluctuations. DIR and STP pins of the driver are connected directly to the Raspberry Pi's GPIO pins and are used in programming to run the motors (see Section 6).

5.3 Sensor

The sensor used to operate the system is the SI1145 digital light sensor. It uses a calibrated light sensing algorithm to measure and calculate light readings in visible, infrared, and ultraviolet spectrums. Due to its low power consumption, this sensor is a feasible option for all day operations only requiring 3 V to run. Using the I^2C protocol, the sensor communicates with the computer to share its readings. The sample output readings of the sensor can be seen in Figure 5 below. The only required output for the system to operate is the UV index calculation that is given as a decimal number on the UV index scale.

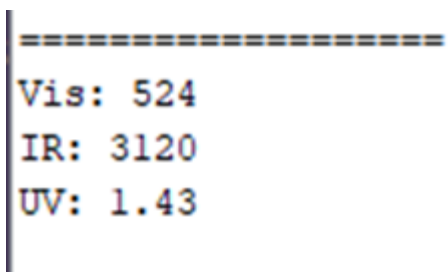


Figure 5. Sample UV reading

5.4 Display

The original goal for the LCD screen was to operate as an informational display for the adults of Kids on Campus to track their exposure to solar radiation. Through the design process it was decided to also use the display as a way for children to interact with the system. As a result a 3.5" LCD screen that supports up to 1920x1280 resolution was chosen. It connects directly to the Raspberry Pi using HDMI cable and proper pin connections. With correct drivers, the display can become a touch sensitive screen that can be operated using a stylus.

The code used to display UV information is listed in the Appendix E. Using the open-source API from the United States Environmental Protection Agency, a database containing hourly UV readings for the day can be extracted. This information is then used and visually organized to display on the screen. Using techniques of color coordination, safe and harmful hours are separated based on the color gradient, green being the safest and red being the least. Figure 6 is a 3D model visualization of the display's operation principle.

The primary concert for the display was its ability to withstand different weather conditions. In order to achieve that an IP65 Junction box may be used with a clear ABS plastic cover to ensure a transparent and unobstructed view of the display. For the sake of accessibility, a hinged box is recommended as it allows for easy access for repairs and diagnostics.

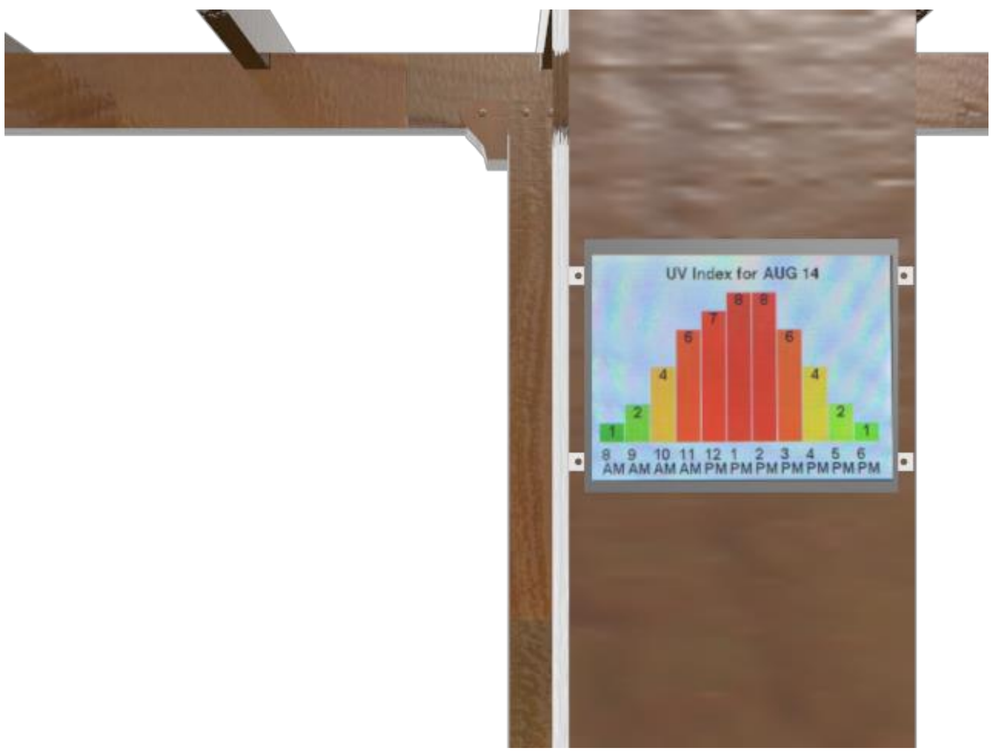


Figure 6. Information display

Section 6 - Programming

This subsection describes the path our project group took in writing the code for our actuated system. We also show the flow chart we created in order to proceed with our code as we felt that the flowchart was the best way to go about figuring out how we might orient our code exactly in order for it to work properly with our system. In order to properly actuate our system given input from a UV index sensor, we implemented an iterative loop that allows for continuous testing of various conditions, in this case the degree to which the project area experiences UV exposure.

The microcontroller chosen to control our system is the Raspberry Pi computing chip. We decided to implement python code as it is the easiest language to understand, and most Raspberry Pi's come preloaded with a python library. Furthermore, by using python over any other code, it is much easier to control the GPIO pins through python than most other languages as immediate use and implementation of those pins is not made as easy by other languages. Much of deciphering how our code might operate throughout the day came from multiple iterations of our conceptual code flowchart, finalized and shown below in Figure 7.

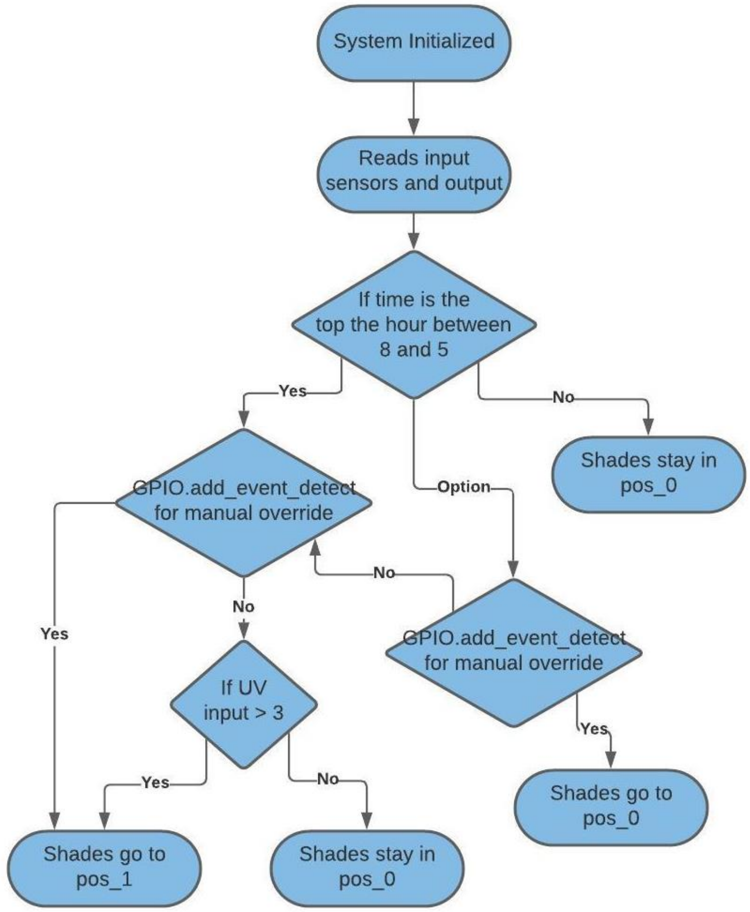


Figure 7. Shading mechanism operation flowchart

Our GPIOs, or general-purpose input output pins, would need to be implemented in our code in order for the code to work properly and deliver the features that our client desires. The purpose of the event detections from these pins is to break the system from the loop to perform a separate function, exactly like how a manual override might operate. The first “if” loop checks to ensure that the time of day is during the hours of operation of Kids on Campus, as we do not need to actuate our system outside of those designated times. Once through this first loop, the code then checks for the dual manual override functions, but when left untriggered, the loop then checks to see if the UV Index input is over or under 3 to then actuate the system based on this input.

Section 7 - Final Project Overview

This section summarizes all the subsystems described in section before to present a final dynamic shading mechanism solution. The final CAD assembly is presented along with the bill of materials and budget review.

7.1 Final Mechanism

To complete the dynamic shading system a mechanism has to be safely stored. In order to achieve this a 3D modelling software was used. Using the Solidworks 2020 software, the CAD model was created. There are three main parts to the CAD assembly, which can be viewed in Figure 8 below **-** motor housing, roller housing, and the motor plug. Detailed descriptions along with measurements can be found on the drawings of Appendix I**.**

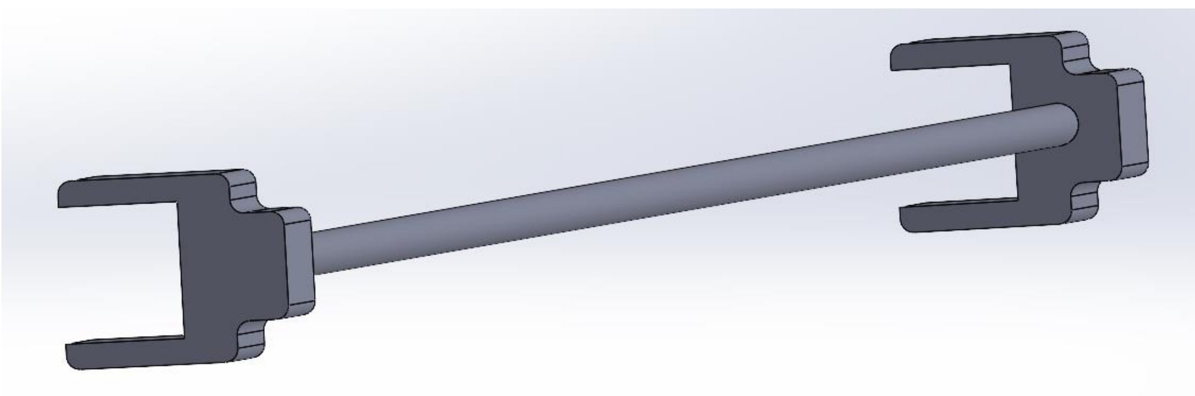


Figure 8. Final CAD assembly of the shading mechanism (10' long, 1x50 scale)

Upon completion, all parts of the CAD assembly were then 3D printed out of PETG material. Walls of the housings were designed to be thicker in order to prevent water from leaking through the material and onto the motors. The final printed settings were as followed - white PETG, 0.2-layer height, 10-20% infill density.

Figure 9. Shading mechanism assembly mounted on the pergola structure

On top and bottom of the motor and roller housings counterbore holes for M4 screws were created in order to ensure fixing points between the housings and the pergola. Stepper motors are placed in the motor housing and have a motor plug attachment on the shaft of the steppers. The plug is then epoxied into the EMT conduit pipe that provides a strength of connection up to 3127 psi. On the other side of the pipe the roller housing is attached simply by plugging in the pipe into the housing. This housing has a hole that is deep enough to secure a sealed fit with the roller.

7.2 Bill of Materials and Budget Considerations

To better organize the program management aspect of the project the bill of materials was created. This allowed us to track and record various materials and items needed for the project to complete. After our original estimations, the budget of $1,500.00 was confirmed and granted by Santa Clara University. With this money we were able to allocate resources on different subsystems based on their needs. From our original market research, we realized that the pergola structure would be the most expensive to build as it included multiple tool rentals that were required for the assembly of the structure.

The final bill of materials can be found in Appendix J. The overall cost of the project, including tool rentals, turned out to be just over $1,000.00. Some of the parts that we were able to reduce spendings on were the pergola structure and the shading fabric. Instead of getting a premade wooden structure, that would double the cost of it, we decided to buy pergola brackets separately and instead purchased and treated wooden planks ourselves. Total savings for the projects equal around $480.00.

Section 8 - Testing and Results

This section describes the path our project group took in testing our project as well as measuring the ambient input in the area where we would be working. Furthermore, in this subsection, we will also discuss how testing, and the results from our testing were beneficial to the project.

8.1 Testing Protocol

At the beginning of the project, we decided on multiple tests that we would need to complete before, during and after the construction of our project. Before testing and brainstorming the testing protocol for the ambient measurements, we decided on the protocols that we would implement in order to test our actuated system. Our first step was to ensure that everything fit within the physical specifications designated for us by our client and ensuring that the mechanism would fit well, we could permanently fix it to the structure, and that the shade would not be too heavy for the system, or cause and adverse risk to the safety of our end-users.

In order to test the proper ambient variables, like UV radiation index, we tested such sensor output in multiple different conditions from low to high sunlight. We applied the same technique to how we tested the UV index sensor, making sure to test under different conditions, as well as to make sure the measurements given by the sensor were the same measurements we would be using in our code among other things. Our main testing protocol was to test every input and output that was a part of our project as well as test each variable under different conditions to get as much data as possible. We used these different data points to compare the differing conditions to one another to see what the overall effectiveness of our system would be given those varying conditions.

8.2 Testing Results

To ensure testing results could be deemed as successful we tied them back to original success metrics that we discussed with our client. Before testing some of the ambient measurements, we began testing the shading mechanism by loosely attaching it to the structure, but not fully securing it to the structure. By doing this, we were able to understand what parts of our shading mechanism we would need to modify before we permanently fixed it to the structure. Such modifications were the width of the motor housings in order to provide a closer and more secure fit. In regards to the motor housing, we also realized that we would need to provide holes in the motor housing that were slightly asymmetrical so that we could use a drill to better permanently fix the mechanism to the structure.

While testing and figuring out which modifications we would need to make to the mechanism, we also realized that we would need to make some modifications to the shade as well. As we were testing the mechanism and motor housings, we attached our shading material to the actuated axel to ensure that the motor would be able to spin the weight of the material but in doing so, we found that that material needed to be weighed down so that it would not flap to vigorously in high wind conditions. As a result of this possibility, we then realized that we would need to add some sort of counter weight to the bottom of our shades so that the wind would not cause it to fly around as much. We also recognized that the counterweight could pose a potential risk so we opted to use a small diameter weighted rod that was either wood or rubber to not cause too much harm should one of the students run into it.

The primary goal was to reduce the amount of harmful solar radiation. During the testing phase of the project, we were able to calculate the overall percent change of UV reduction. Through readings from the SI1145 sensor we found that in the middle of the day when UV is the highest, the shade under our structure decreases the amount of ultraviolet significantly. Figure 10 shows sensor readings during midday conditions outside and under the newly built structure.

Figure 10. Sensor readings outside and under the structure

Vis: 2082
IR: 17158
UV: 9.78

Vis: 562
IR: 3877
UV: 1.63

Figure 10. Sensor readings outside and under the structure

Using the percent change equation (eq.2), we are able to find the overall decrease of UV readings resulted by our system. Harmful solar radiation is decreased by more than 80% using solar shading methods, resulting in a safe space for kids to explore even during the hottest hours of the day.

$$\% \text{ Change} = 100\% * (UV\_under - UV\_outside) / UV\_outside \qquad \text{(eq. 2)}$$

8.3 Issues and Improvements

Upon the delivery of the main structure the client was satisfied with the work done in restructuring and reorganizing the space. The first issue that came up, however, was with the structural part of the system. The fabric that was attached to the top of the pergola came off the anchors that were used to fixate the shade after a night of strong winds. To secure a tighter fit ropes were used that added an extra load-bearing capacity that would withstand poor weather conditions (see Figure 11).

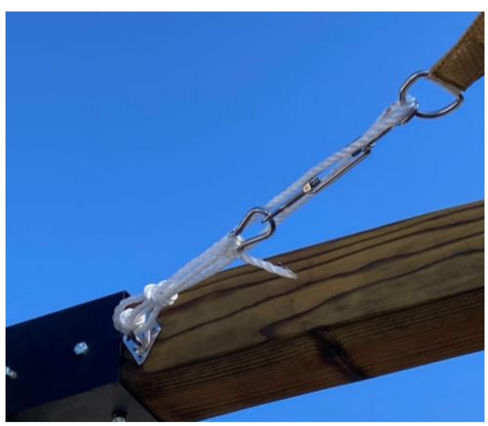


Figure 11. Improved shading fabric attachment

The next issue was figuring out the proper distance for the shading material to rotate. In order to find the correct distance, the fabric was rotated to observe the most optimal translation displacement. The most adequate distance turned out to be about 3 feet off the top of the pergola, allowing for about 5 feet of space between the ground and the bottom of the fabric. This created a direct path for faculty of Kids on Campus to observe the safety and wellbeing of children.

Section 9 - Professional Considerations

In this chapter of our Senior Design Thesis, we discuss the multiple professional considerations that we needed to consider while building our system and throughout the entire design process. Some professional considerations should always include how the team members conduct themselves when encountering any sort of communication with the client as we are representatives of Santa Clara University.

9.1 Ethical Considerations

Our ethical considerations primarily focused on the children of Kids On Campus, as they are the main group of people that we are aiming to serve and benefit through the implementation of our project. As these children are a part of the next generation of leaders and influencers, they will have a great impact on the future, not only of our country but also of our world. This consideration of the next generation led our group to strive to have a positive health impact on these children, and to educate them through the construction and successful completion of our project, hopefully sparking their early and sustained interest in science, technology, engineering and math. Through the spark of this interest, we aim to also educate the children about our system by demonstrating the many different facets that the project possesses, whether it be coding, 3D printing, or the physical construction that interests them most.

By educating these children on the positive impact that our project has on their lives - allowing them to be outdoors more often with a lower risk of over-exposure to harmful UV radiation - we hope to show them that they too can have a great impact on their community, and perhaps an even greater one than ours given the advancement in technology that is likely to occur between today and when they would have the opportunity to undertake such a project.

9.2 Green Technology

In this subsection, we will discuss the reasons as to why our group approached this project with the idea of implementing green energy to make our project green technology.

An important consideration we had in the initial design phase of our project was whether or not we would implement the use of green technology and renewable energy, such as solar power. Rather than using power from the power grid at Kids on Campus, we integrated a solar panel with a reserve battery into our system to demonstrate sustainability to the children at Kids on Campus. To fully demonstrate the capacity for sustainability that our project and solar power has, we showed that the power drawn by our system is less than the power delivered by the solar panel and its reserve battery (see Table 4), which optimized the sustainability of our system. The external battery is charged by the solar panel for use on cloudier days when the solar panel is unable to output the power needed for the system to run properly. Our goal is that the sustainability demonstrated by our project will inspire the children of Kids on Campus to take a high level of interest in the study of science, technology, engineering and mathematics, to positively benefit the communities around them one day, as well as communities all over the world.

9.3 Client Verification and Validation

Over the course of our project, and any design project for that matter, feedback from the client is of the utmost importance for several reasons.

The first, and most significant reason for the importance of client feedback is to verify the next steps in the project before proceeding so that they are aware of what is currently going on in the project and what is coming next. During verification communications with our client, we also included validation communications so that we could ensure that the design, features and aesthetic of the structure fit the expectations for the project given to us by our client.

The second reason as to the importance of feedback from the client is similar to the first with regard to feedback from clients. It is important for us to get feedback from the client so that they can understand the current steps we are taking, but it is also important that the feedback includes any additional features or features that may not matter as much to our client.

Feedback, validation, and verification are three incredibly important professional considerations as the design process is meant to deliver a product to a client that meets the expectations that they set out for the project team and solves the problem that they asked the team to solve.

Section 10 – Conclusion and Recommendations

This section concludes our project, summarizes its many aspects, discusses future uses and implementations and explains some of the key lessons we learned from inception to completion.

10.1 Summary

The Senior Design Project took three quarters to complete, and the procedure resembled five steps of the design thinking process. Through our communication with the client, we were able to empathize with the representatives of Kids on Campus to define success metrics. This helped us ideate various solutions from which the most feasible one was picked. As prototyping began, we had to regularly return to ideation in order to improve our product according to defined metrics. Only through the last step of design thinking, testing, were we able to truly define the scope of the problem and visualize and fine-tune a better solution.

Despite various challenges along the way, our overall system architecture was brought to life and actuated. The results of the project accomplished set goals that were defined in success metrics while being more than 30 % under the initially planned and granted budget. With a permanent structure in place, the playground area is now safer to use and virtually free to operate.

10.2 Future Uses, Improvements and Recommendations

To ensure the longevity of the system more testing must be completed. One of the project subsystems that requires more data is battery testing under long-term conditions. We suggest testing and carefully analyzing the data that the solar charge controller presents regarding the solar panel current output. Battery charge and discharge needs more examination to provide data on the autonomy of the project.

Another issue that we studied, and which deserves further testing and analysis, is the tracking system for the shading mechanism. A stop sensor may be implemented to cause an intervention in the actuation process. As the project accomplishes its final prototype form, the next step will be to create a final product. The solution may be implemented with less space-consuming parts, such as substituting Raspberry Pi 4 with its smaller sibling, Raspberry Nano. With virtually identical specifications, Raspberry Nano consumes much less space, allowing for a smaller and more elegant alternative, and a more pleasing, streamlined aesthetic.

Finally, the project's user-interface requires further adjustments. One of the ways to improve the interactive aspect of the project is to implement correct display drivers to allow for its touch screen functionality. This can create an engaging component that children can play with. The potential surplus of power generated allows for a more complex and detailed system. In addition, through additional code manipulation, each of the rollers may be rotated separately, based on the sun's elevation relative to the pergola structure.

10.3 Lessons Learned

Throughout the course of this project, we learned many important lessons, the largest of which has been the value and importance of communication between teammates, the client, and our advisor. Having lost a third teammate to poor, only occasional communication, caused by a large time zone difference, his lack of access to reliable internet connectivity and his remote physical location relative to Santa Clara, the importance of constant, accurate communication became highly apparent to us, as even the simplest communications can optimize efficiency, project success and understanding between teammates.

Another valuable lesson that we learned is the importance of trying to see the project from the perspective of both the client and the end-user. At first, we did consider how the end-users, the children, and staff at Kids on Campus, might impact our project, which was challenging, due to their lack of presence during the COVID-19 global pandemic. Through communication with our project partner and our advisor, we began to understand that similar to the risks our project construction posed as a result of the interaction that the children will have with it, we needed to consider any and all interactions that the kids would have with our structure once it is completed and fully in-service. One specific interaction we began to consider was the manual override button that we implemented in our project, and if the over-use or rapid pressing of the button might negatively impact our code. As a result of this consideration, we made the decision to add a failsafe for this type of interaction, which is called a delay in the code, with a defined number of milliseconds that the code will be delayed in the parenthesis following the command.

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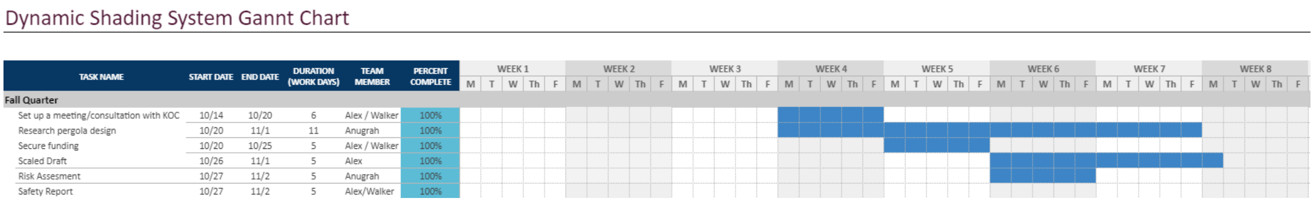
Appendices

Appendix A: Original Prototype (1x10 scale)

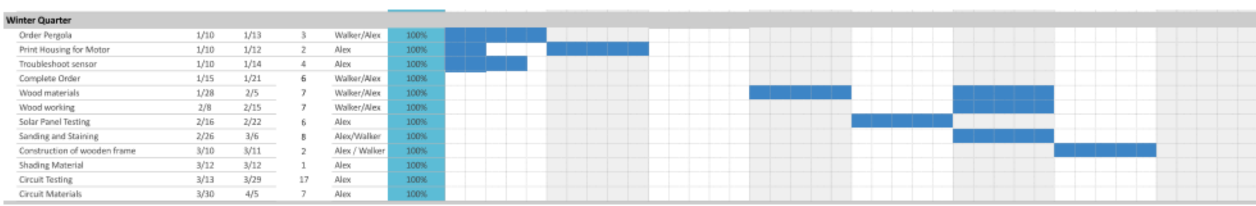
Figure A-1. Original prototype

Appendix B: Gantt Chart



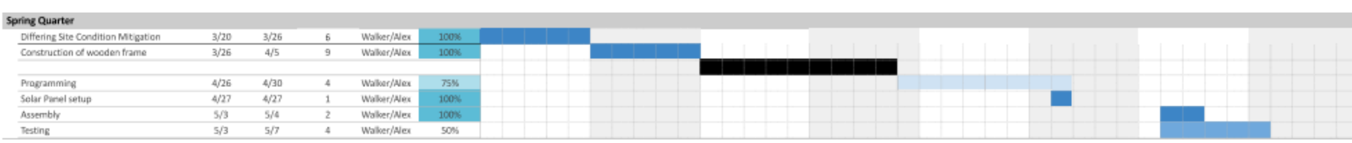
TASK NAME	START DATE	END DATE	DURATION (WORK DAYS)	TEAM MEMBER	PERCENT COMPLETE
Fall Quarter					
Set up a meeting/consultation with KOC	10/14	10/20	6	Alex / Walker	100%
Research pergola design	10/20	11/1	11	Anugrah	100%
Secure funding	10/20	10/25	5	Alex / Walker	100%
Scaled Draft	10/26	11/1	5	Alex	100%
Risk Assesment	10/27	11/2	5	Anugrah	100%
Safety Report	10/27	11/2	5	Alex/Walker	100%

Figure B-1: Fall quarter planning



Winter Quarter					
Order Pergola	1/10	1/13	3	Walker/Alex	100%
Print Housing for Motor	1/10	1/12	2	Alex	100%
Troubleshoot sensor	1/10	1/14	4	Alex	100%
Complete Order	1/15	1/21	6	Walker/Alex	100%
Wood materials	1/28	2/5	7	Walker/Alex	100%
Wood working	2/8	2/15	7	Walker/Alex	100%
Solar Panel Testing	2/16	2/22	6	Alex	100%
Sanding and Staining	2/26	3/6	8	Alex/Walker	100%
Construction of wooden frame	3/10	3/11	2	Alex / Walker	100%
Shading Material	3/12	3/12	1	Alex	100%
Circuit Testing	3/13	3/29	17	Alex	100%
Circuit Materials	3/30	4/5	7	Alex	100%

Figure B-2: Winter quarter planning



Spring Quarter					
Differing Site Condition Mitigation	3/20	3/26	6	Walker/Alex	100%
Construction of wooden frame	3/26	4/5	9	Walker/Alex	100%
Programming	4/26	4/30	4	Walker/Alex	75%
Solar Panel setup	4/27	4/27	1	Walker/Alex	100%
Assembly	5/3	5/4	2	Walker/Alex	100%
Testing	5/3	5/7	4	Walker/Alex	50%

Figure B-3: Spring quarter planning

Appendix C: Project Hazard Assessment

HAZARDOUS CONDITIONS/PROCESSES/ACTIVITIES		
Electrical Hazards ☐Electrical parts and assemblies > 50V or high current ■Batteries ■Control Panels	**Mechanical Hazards** ■Power tools and equipment ■ Machine guarding/power transmission – gears, rotors, wheels, shafts, belt/chain drives, rotating parts, pinch points ☐Robotics ■Sharp Objects ☐ Stored Energy (springs, gravity, pneumatic, hydraulic, pressure)	**Physical Hazards** ☐ Extreme temps (high temp fluids: water > 160 °F, steam, hot surfaces > 140 °F, cryogenic fluids ☐ Material handling of heavy objects ■ Elevated heights (scaffolding, ladders, roofs, lifts, etc.) ☐ Overhead falling objects (cranes, hoists, drones, projectiles, etc.) ☐ Confined Spaces ■Airborne Dusts ☐Bonding / Grounding ☐Electrostatic Discharge
Reaction Hazards ☐Explosive ☐Exothermic, with potential for fire, excessive heat, or runaway reaction ☐Endothermic, with potential for freezing solvents decreased solubility or heterogeneous mixtures ☐Gases Produced ☐Hazardous reaction intermediates/products ☐Hazardous side reactions	**Hazardous Processes** ☐Generation of air contaminants (gases, aerosols, or particulates) ☐Heating Chemicals ■Large mass or volume ☐Pressure > Atmospheric ☐Pressure < Atmospheric ☐Scale-up of Reaction ☐Metal Fabrication (welding, cutting, drilling, etc.), Soldering, ■Construction/Assembly, etc.	**Other Hazards** ■Noise > 80 dBA ☐Vehicle traffic ☐Hazardous waste generation ☐Other (list):

HAZARDOUS AGENTS			
Physical Hazards Of Chemicals	**Health Hazards of Chemicals**	**Non-Ionizing Radiation**	**Biohazards**
☐Compressed Gases ☐Cryogens ☐Explosives ☐Flammables ☐Oxidizers ☐Peroxides or Peroxides Formers ☐Pyrophorics ■Water Reactives	☐Acute Toxicity ☐Carcinogens ☐Nanomaterials ☐Reproductive Toxins ☐Respiratory or Skin Sensitization ☐Simple Asphyxiant ☐Skin Corrosion/ Irritation ☐Hazards Not Otherwise Classified	☐Lasers ☐Magnetic Fields (e.g. NMR) ☐RF/Microwaves ☐UV Lamps	☐Bsl-2 Biological Agents ☐rDNA ☐Human Cells, Blood, BBP ☐Animal Work ☐Other (List):

Figure C-1: Hazard checklist

Hazardous Activity, Process, Condition, or Agent (identified from previous page):
Summary of Procedure or Tasks: We will be working with power tools to assemble our pergola structure. As our pergola will cover a large area of Kids on Campus' playground, we must also account for the structure's size and weight.
Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk): - Construction/Assembly, etc. - Elevated heights (scaffolding, ladders, roofs, lifts, etc.) - Large mass or volume - Power tools
Hazard Control Measures (what you will do to eliminate the hazard or minimize risks): - Safe working procedure, supporting each other on ladders

Hazardous Activity, Process, Condition, or Agent (identified from previous page):
Summary of Procedure or Tasks: While building we must form concrete supports in the ground to help the pergola's integrity and longevity. We also must make sure that there are no sharp edges on the structure that would have the potential to cause any injury.
Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk): - Water Reactives - Power tools - Airborne dusts (from the concrete primarily)
Hazard Control Measures (what you will do to eliminate the hazard or minimize risks): Using Quikrete instead of normal concrete Wearing safety goggles Masks and gloves

Hazardous Activity, Process, Condition, or Agent (identified from previous page):
Summary of Procedure or Tasks: While combining our circuit components, we must run the code several times to make sure that it runs properly with each circuit component and doesn't overload any other circuit component.
Describe Hazards (why is the procedure hazardous or what can go wrong – what is the risk): - Batteries (9V) - Control Panels
Hazard Control Measures (what you will do to eliminate the hazard or minimize risks): Work in the dry conditions

Figure C-2: Description of potential hazards

SAFETY EQUIPMENT and PPE
Select the appropriate PPE and safety supplies you will need for the project (Check all that apply)

■ Appropriate street clothing (long pants, closed-toed shoes)

■ Gloves; indicate type: ____Thermal resistant, tear resistant______

■ Safety glasses/ goggles

☐ Face shield and goggles

☐ Lab coat

■ Hearing protection

☐ Fire extinguisher

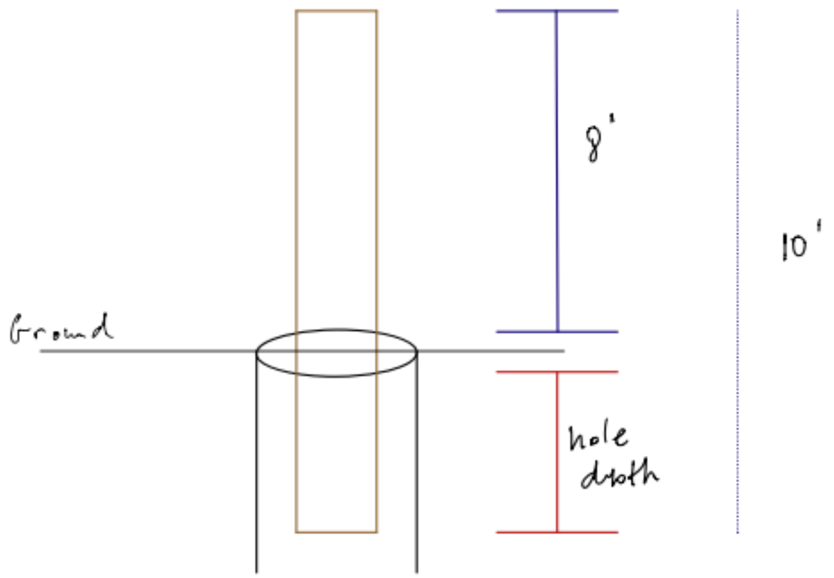
☐ Eyewash/safety shower

☐ Spill kit

■ Other (list): face mask for COVID-19 as well as concrete dust

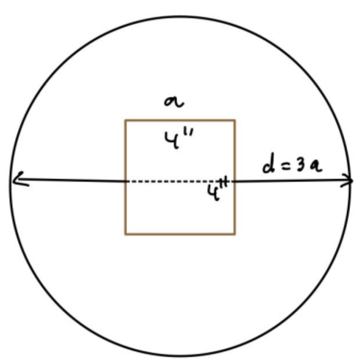
Figure C-3: Required safety equipment and PPE

Appendix D: Construction Hole Calculation



$$\text{Hole depth} = \frac{1}{4} \cdot \text{Height above ground}$$

$$\Rightarrow \text{Hole depth} = \frac{1}{4} \cdot 8 = \boxed{\text{2 feet deep}}$$



diameter of the hole = 12" = 1 foot

Figure D-1: Hole depth and width calculations

Appendix E: Display Code for UV index

```
"""
PyPortal UV Index display

Adafruit invests time and resources providing this open source code.
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products from Adafruit!

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"""

import time
import json
import board
import displayio
from adafruit_pyportal import PyPortal
from adafruit_display_shapes.rect import Rect
from adafruit_display_text.Label import Label
from adafruit_bitmap_font import bitmap_font

try:
    from secrets import secrets
except ImportError:
    print("""WiFi settings are kept in secrets.py, please add them there!
the secrets dictionary must contain 'ssid' and 'password' at a minimum""")
    raise

MAX_BAR_HEIGHT = 160
MARGIN = 10
SPACE_BETWEEN_BARS = 1

COLORS = [0x00FF00, 0x83C602, 0xa2CF02,
          0xF7DE03, 0xF6B502, 0xF78802,
          0xF65201, 0xEA2709,
          0xDA0115, 0xFC019E, 0xB548FF,
          0x988FFE, 0x7EA7FE, 0x66BFFD, 0x4BD9FF]

cwd = ("/"+__file__).rsplit('/', 1)[0]

CAPTION_FONT_FILE = cwd+'/fonts/Helvetica-Bold-16.bdf'
BAR_FONT_FILE = cwd+'/fonts/Arial-Bold-12.bdf'

#pylint:disable=line-too-long
url = 'https://enviro.epa.gov/enviro/efservice/getEnvirofactsUVHOURLY/ZIP/95050/JSON'.format(secrets['zip']) # extracting
UV readings for Santa Clara location using the index from database
#pylint:enable=line-too-long

def extract_hour(date_time):
```

```
    """Extract the hour in a format to use for display:
    :param date_time: the timestamp from EPA UV readings
    """
    split_date_time = date_time.split()
    hour = split_date_time[1]
    suffix = split_date_time[2]
    if hour[0] == '0':
        hour = hour[1]
    return '\n'.join([hour, suffix])

def extract_date(date_time):
    """Extract the date in a format to use for display:
    :param date_time: the timestamp from EPA UV readings
    """
    return ' '.join(date_time.split('/')[0:2])

pyportal = PyPortal(url=url,
                    status_neopixel=board.NEOPIXEL,
                    default_bg=0xFFFFFF,
                    caption_font=CAPTION_FONT_FILE)

canvas = displayio.Group(max_size=36)
pyportal.splash.append(canvas)
bar_font = bitmap_font.load_font(BAR_FONT_FILE)

while True:
    json_payload = ''
    try:
        json_payload = pyportal.fetch()
        raw_data = json.loads(json_payload)
    except (ValueError, RuntimeError) as ex:
        print('Error: ', ex)
        if isinstance(ex, ValueError):
            print('JSON:', json_payload)
        print('Retrying in 10 minutes')
        time.sleep(600)
        continue
    data = []
    for d in raw_data:
        if d['UV_VALUE'] > 0:
            entry = {}
            entry['hour'] = extract_hour(d['DATE_TIME'])
            entry['value'] = int(d['UV_VALUE'])
            data.append(entry)
    the_day = raw_data[0]['DATE_TIME']
    pyportal.set_caption('UV Index for {0}'.format(extract_date(the_day)),
                         (80, 20),
                         0x000000)
    number_of_readings = len(data)
    whitespace = (number_of_readings - 1) * SPACE_BETWEEN_BARS + 2 * MARGIN
    bar_width = (320 - whitespace) // number_of_readings
    max_reading = max([d['value'] for d in data])

    while len(canvas) > 0:
```

```
    canvas.pop()

for i, reading in enumerate(data):
    bar_height = (MAX_BAR_HEIGHT * reading['value']) // max_reading
    x = int(MARGIN + i * (bar_width + SPACE_BETWEEN_BARS))
    canvas.append(Rect(x, 200 - bar_height,
                   bar_width, bar_height,
                   fill=COLORS[reading['value']]))
    canvas.append(Label(bar_font,
                    x=x+3, y=220,
                    text=reading['hour'],
                    color=0x000000,
                    line_spacing=0.6))
    canvas.append(Label(bar_font,
                    x=x+(bar_width//2)-4, y=208-bar_height,
                    text=str(reading['value']),
                    color=0x000000))

time.sleep(3600)          #refresh hourly
```

Appendix F: Code to actuate our motors

```
import schedule
import sys
import time
import RPi.GPIO as GPIO
import SI1145.SI1145 as SI1145

sensor = SI1145.SI1145()
while True:
   vis=sensor.readVisible()
   IR=sensor.readIR()
   UV=sensor.readUV()
   uvIndex=UV / 100.0
   print 'Vis:' + str(vis)
   print 'IR:' + str(IR)
   print 'UV Index:' + str(uvIndex)

   time.sleep(3)</pre>

GPIO.setmode(GPIO.BCM)
GPIO.setmode(GPIO.BOARD)

control_pins = [7,11,13,15]
for pin in control_pins:
 GPIO.setup(pin, GPIO.OUT)
 GPIO.output(pin, 0)
halfstep_seq = [
 [1,0,0,0],
 [1,1,0,0],
 [0,1,0,0],
 [0,1,1,0],
 [0,0,1,0],
 [0,0,1,1],
 [0,0,0,1],
 [1,0,0,1]
]
for i in range(512):
 for halfstep in range(8):
   for pin in range(4):
     GPIO.output(control_pins[pin], halfstep_seq[halfstep][pin])
   time.sleep(0.001)

GPIO.setup(15, GPIO.IN, pull_up_down=GPIO.PUD_UP)
GPIO.setup(27, GPIO.IN, pull_up_down=GPIO.PUD_DOWN)

def shade_down(channel):
   # Use BCM GPIO references
   # instead of physical pin numbers
   GPIO.setmode(GPIO.BCM)

   # Define GPIO signals to use
   # Physical pins 11,15,16,18
   # GPIO17,GPIO22,GPIO23,GPIO24
   StepPins = [17, 22, 23, 24]
```

```
# Set all pins as output
for pin in StepPins:
    print
    "Setup pins"
    GPIO.setup(pin, GPIO.OUT)
    GPIO.output(pin, False)

# Define advanced sequence
# as shown in manufacturers datasheet
Seq = [[1, 0, 0, 1],
       [1, 0, 0, 0],
       [1, 1, 0, 0],
       [0, 1, 0, 0],
       [0, 1, 1, 0],
       [0, 0, 1, 0],
       [0, 0, 1, 1],
       [0, 0, 0, 1]]

StepCount = len(Seq)
StepDir = -2

# Read wait time from command line
if len(sys.argv) & gt;1:
    WaitTime = int(sys.argv[1]) / float(1000)
else:
    WaitTime = 10 / float(1000)

# Initialise variables
StepCounter = 0

# Start main loop
while True:

    print
    StepCounter,
    print
    Seq[StepCounter]

    for pin in range(0, 4):
        xpin = StepPins[pin]  #
        if Seq[StepCounter][pin] != 0:
            print
            " Enable GPIO %i" % (xpin)
            GPIO.output(xpin, True)
        else:
            GPIO.output(xpin, False)

    StepCounter += StepDir

    # If we reach the end of the sequence
    # start again
    if (StepCounter & gt;=StepCount):
        StepCounter = 0
    if (StepCounter & lt;0):
        StepCounter = StepCount + StepDir

    # Wait before moving on
```

```
        time.sleep(WaitTime)

def shade_up(channel):
    # Use BCM GPIO references
    # instead of physical pin numbers
    GPIO.setmode(GPIO.BCM)

    # Define GPIO signals to use
    # Physical pins 11,15,16,18
    # GPIO17,GPIO22,GPIO23,GPIO24
    StepPins = [17, 22, 23, 24]

    # Set all pins as output
    for pin in StepPins:
        print
        "Setup pins"
        GPIO.setup(pin, GPIO.OUT)
        GPIO.output(pin, False)

    # Define advanced sequence
    # as shown in manufacturers datasheet
    Seq = [[1, 0, 0, 1],
           [1, 0, 0, 0],
           [1, 1, 0, 0],
           [0, 1, 0, 0],
           [0, 1, 1, 0],
           [0, 0, 1, 0],
           [0, 0, 1, 1],
           [0, 0, 0, 1]]

    StepCount = len(Seq)
    StepDir = 2

    # Read wait time from command line
    if len(sys.argv) & gt;1:
        WaitTime = int(sys.argv[1]) / float(1000)
    else:
        WaitTime = 10 / float(1000)

    # Initialise variables
    StepCounter = 0

    # Start main loop
    while True:

        print
        StepCounter,
        print
        Seq[StepCounter]

        for pin in range(0, 4):
            xpin = StepPins[pin]   #
            if Seq[StepCounter][pin] != 0:
                print
                " Enable GPIO %i" % (xpin)
                GPIO.output(xpin, True)
            else:
```

```
                GPIO.output(xpin, False)

        StepCounter += StepDir

        # If we reach the end of the sequence
        # start again
        if (StepCounter & gt;=StepCount):
            StepCounter = 0
        if (StepCounter & lt;0):
            StepCounter = StepCount + StepDir

        # Wait before moving on
        time.sleep(WaitTime)

def SD_Function(channel):
   if stepper=pos0:
        GPIO.add_event_detect(15, GPIO.FALLING, callback=shade_down(),
bouncetime=300)
        if uvIndex>3:
            GPIO.add_event_detect(27, GPIO.FALLING, callback=shade_up(),
bouncetime=300)
            stepper=pos1
        else GPIO.add_event_detect(27, GPIO.FALLING,
callback=shade_up(), bouncetime=300)
   else GPIO.add_event_detect(15, GPIO.FALLING, callback=shade_down(),
bouncetime=300)

GPIO.cleanup()

schedule.every(1).hours.do(SD_Function)
schedule.every().monday.at("8:00").do(SD_Function)
schedule.every().tuesday.at("8:00").do(SD_Function)
schedule.every().wednesday.at("8:00").do(SD_Function)
schedule.every().thursday.at("8:00").do(SD_Function)
schedule.every().friday.at("8:00").do(SD_Function)

running=True
def test():
   global running
   running=False
   return schedule.CancelJob
schedule.every().day.at("17:00").do(test)
while running:
   schedule.run_pending()
   time.sleep(1)

while True:
   schedule.run_pending()
   time.sleep(1)
```

Appendix G: Battery Charging Circuit

Figure G-1: Battery charging circuit

Appendix H: Motor Circuit

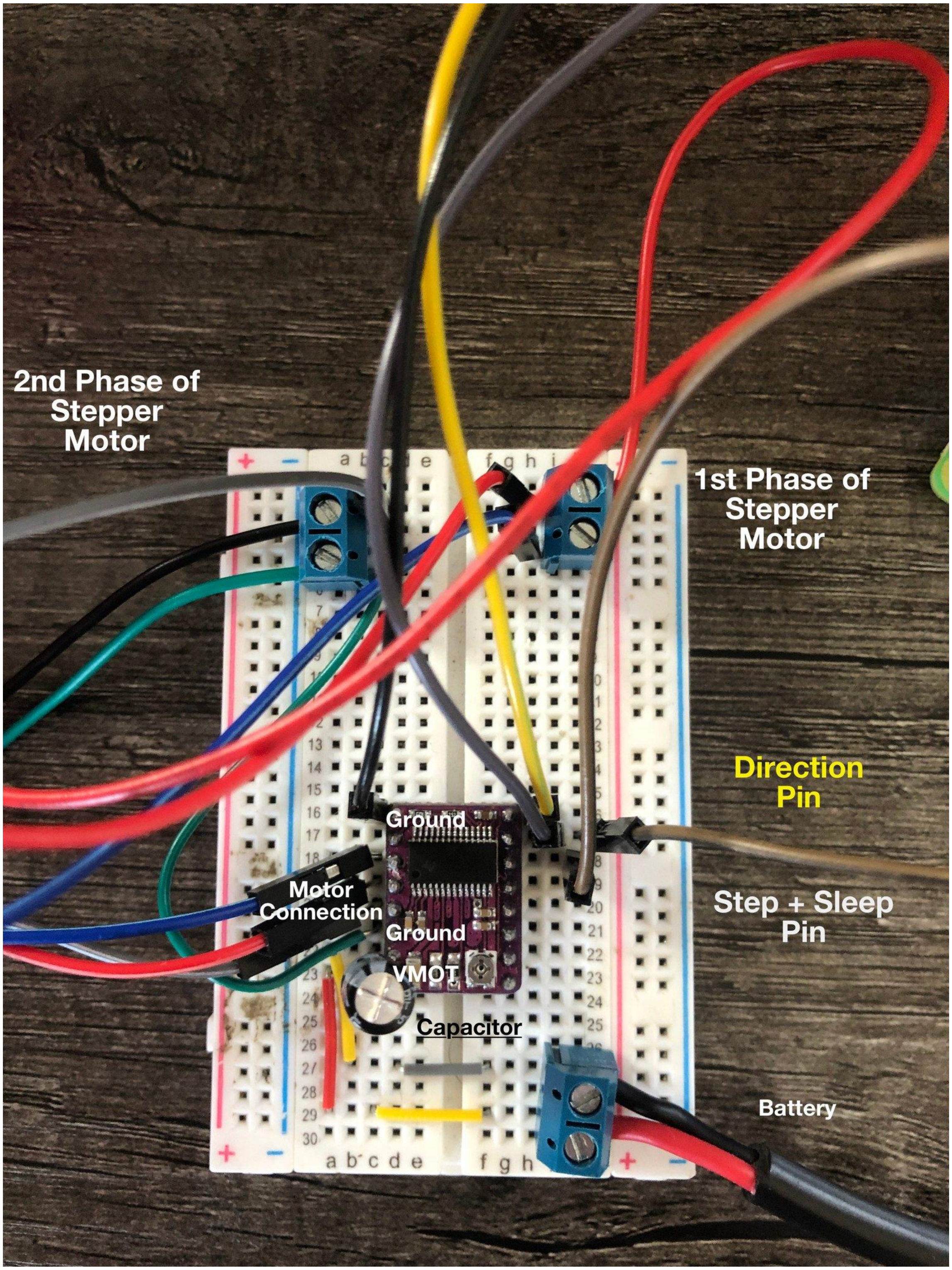


Figure H-1: Motor driving circuit

Appendix I: CAD Drawings

I.1: Final CAD Assembly (1x50 scale, units in feet)

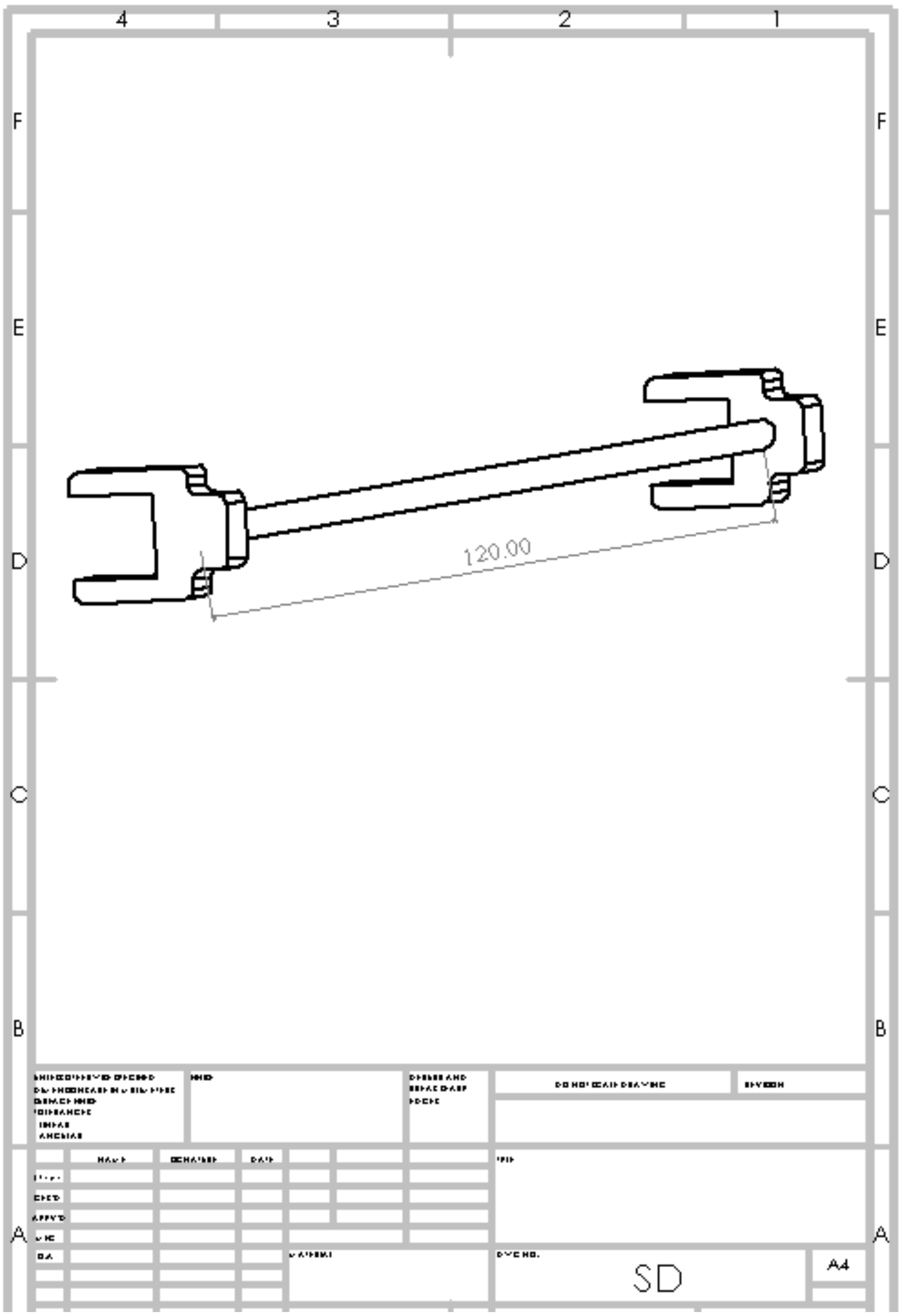


Figure I-1: 1x50 Scaled CAD assembly

I.2: Motor Housing (units in inches)

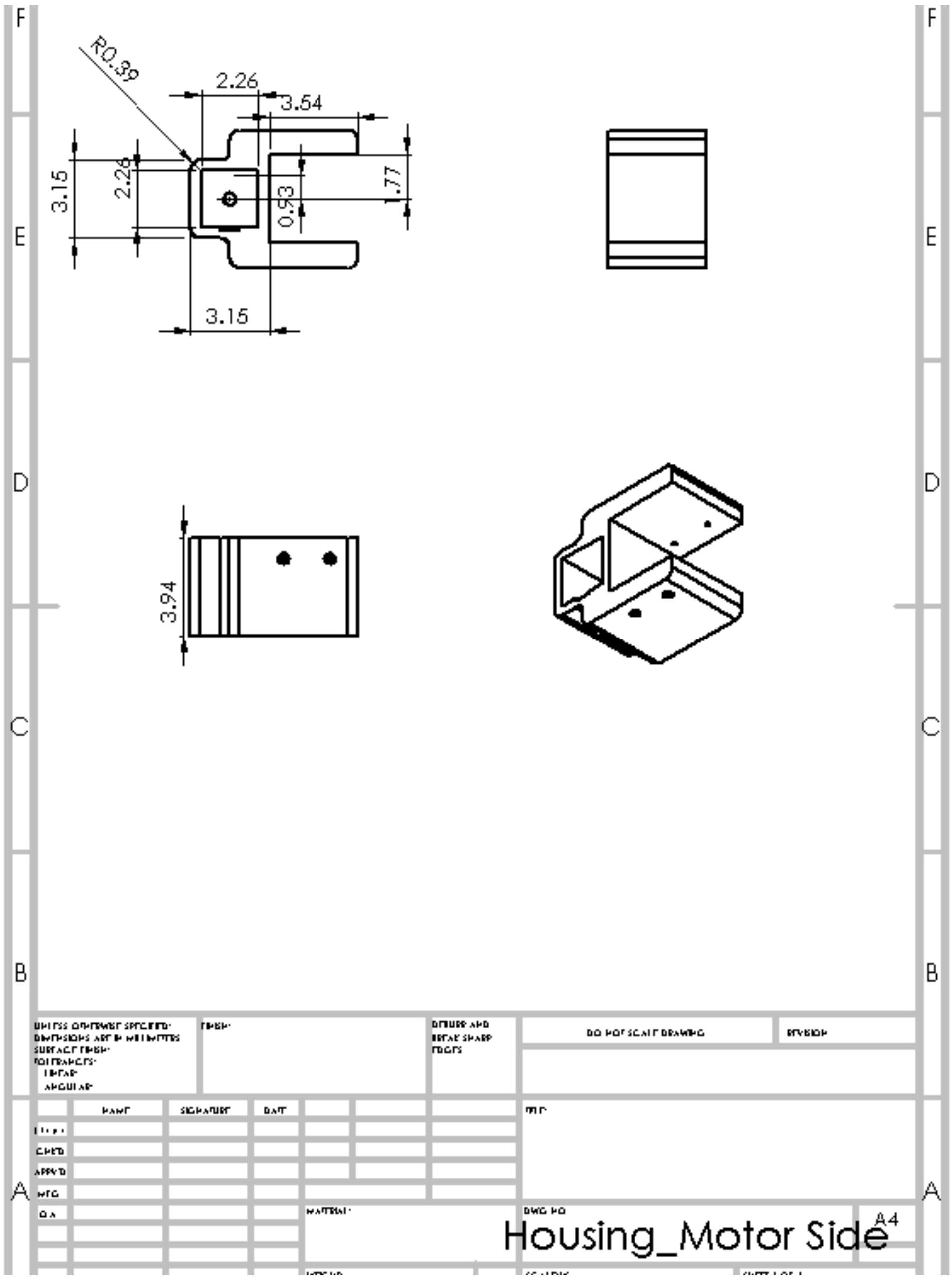


Figure I-2: Motor housing CAD model (in inches)

I.3: Roller Housing (units in inches)

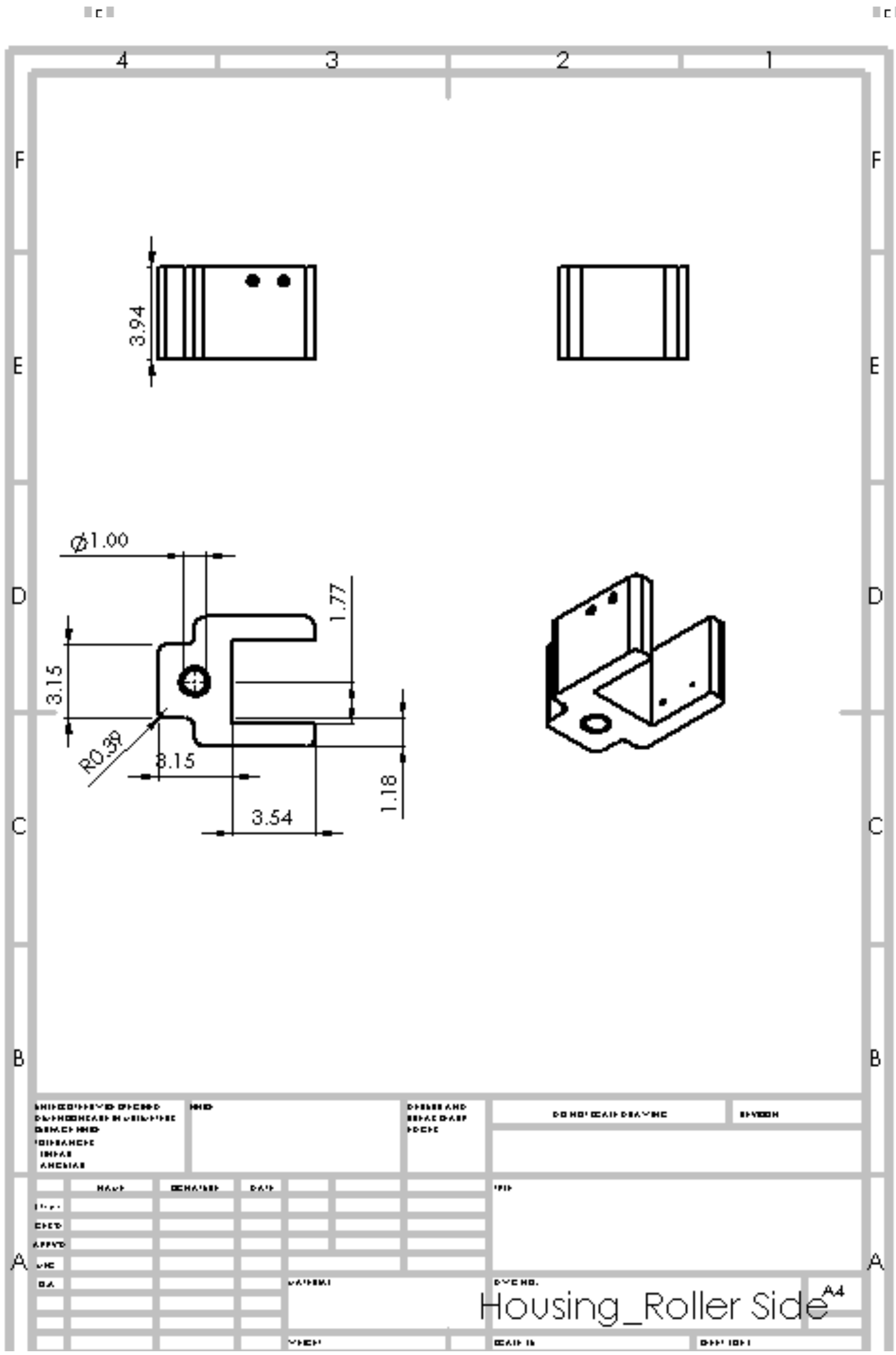


Figure I-3: Roller housing CAD model (in inches)

I.4: Motor Plug (units in inches)

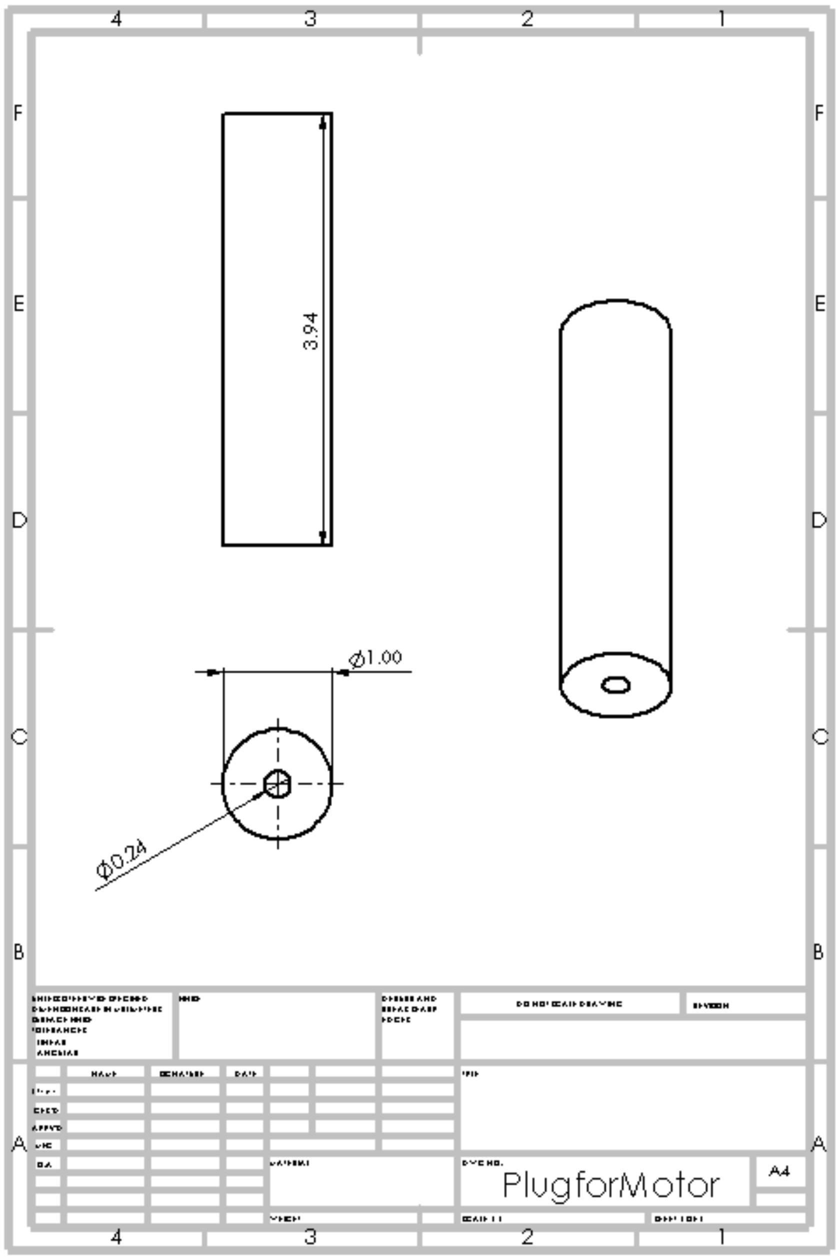


Figure I-4: Motor plug CAD model (in inches)

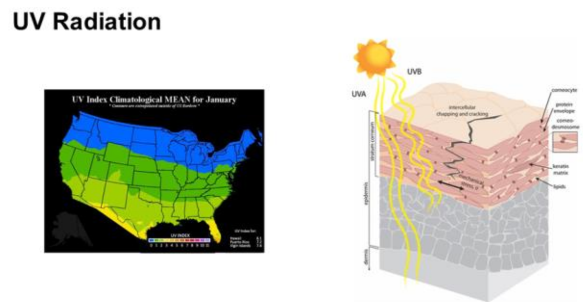
Appendix J: Bill of Materials

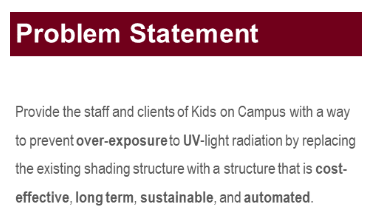
Table J-1: Bill of Materials

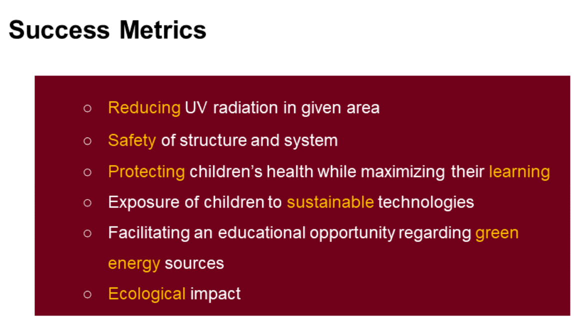
Item Name	Description	Quantity	Total Price ($)
Battery	12V 6800mAh lithium ion rechargeable battery pack	1	24.99
Breadboard	Solder Board	1	15.99
Buck Converter for Circuit	Step-down module	1	12.99
Concrete	Quikrete	12	63.00
Buck Converter for Pi	12V-5V USB-C	1	11.99
DC Power Cable (Female Plug to Bare Wire)	3FT	1	8.99
DC Power Cable (Male Plug to Bare Wire)	20” 18AWG	1	36.99
Display	3.5” LCD Display	1	34.99
Fabric (Top)	10’x10’ Sun Shade	1	34.99
Fabric (Mechanism)	8’x50’ Brown Sun Shade	1	73.98
Junction Box	ABS Plastic Dustproof Waterproof IP65	1	11.99
Motors	Nema 23 Stepper Motor 3.0A	2	63.96
Motor Driver	DRV8825	1	10.31
Pergola Brackets		1	391.99
Pergola Wood	4”x4”, 10’	4	66.01
Pergola Wood	4”x4”, 12’	4	76.40

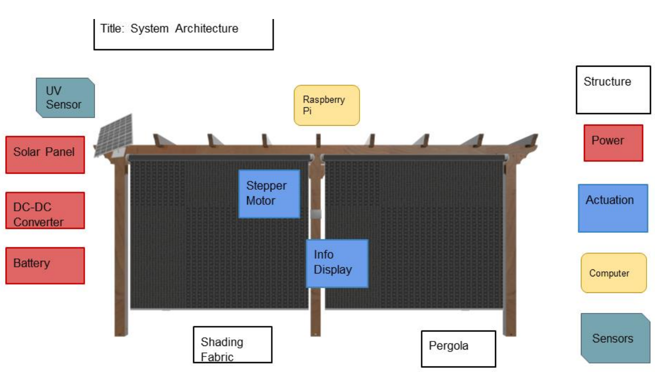
Power Cable	100' 16AWG	1	36.99
Push Button	25Pcs Momentary Tact Tactile Button	1	7.89
Roller Pipe	1" x 10' EMT Conduit Pipe	2	29.90
Shade Hardware Kit		1	17.99
Solar Panel	100W Kit-12v Monocrystalline Portable Mono Solar Panel Starter Kit	1	164.99
Solar Panel Mount	Heavy Duty Double Arm Pole Wall Mount	1	64.50
Wire Kit	140 PCS U-Shape Jumper Wire	1	8.99
Wood Preservative	Copper-Green 1 gal	1	24.95
Total Cost			**984.44**
Equipment Rental			**37.00**
Total Cost with Equipment Rental			**1021.44**
Total Budget			**1500.00**
Total Savings			**478.56**

Appendix K: Final Senior Design Presentation (in Left to Right Order):









Wood Preparation (Sanding and Staining)

Construction

Step 1:

Step 2:

Construction (continued)

Step 3:

Step 4:

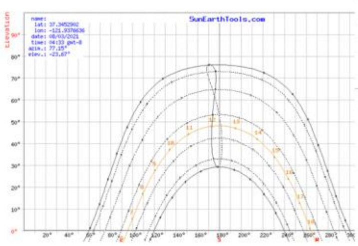
Solar Panel

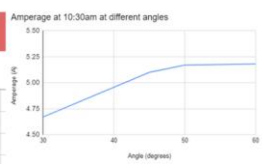
- 100Watt solar panel
- 12V controller

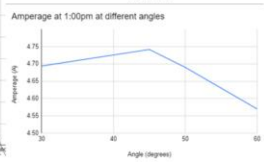
10:30am current in Amps

10:30am shaded area current in Amps

Solar Panel Testing







Solar Panel Charging Circuit

Circuitry

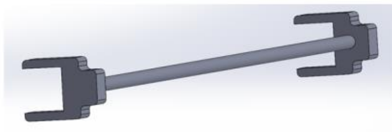
- **Battery Circuit:**
- 16 AWG power wires with UV and weather resistant PVC covering
- 16 AWG Male Plug to Bare Wire from solar charger to battery
- 16 AWG Female Plug to Bare Wire from battery to Raspberry Pi
- IP65 Junction box for battery storage

Circuitry

- **Raspberry Pi Circuit:**
- DC-DC 12V to 5V 3A step-down converter
- DRV8825 Stepper Motor Driver
- Bipolar Stepper Motor 2Nm

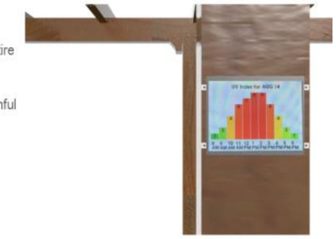
Actuation

- 10 feet metal conduit pipe acting as a roller
- 95% UV resistant fabric



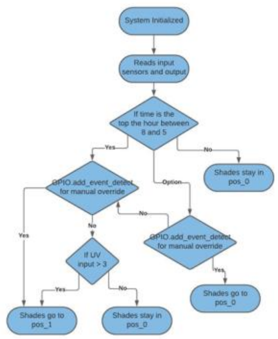
Display

- 3.5-Inch HD display
- Projecting UV index per hour for an entire day
- Use of various colors to represent harmful hours



Programming

- Main circuit component
  - Raspberry Pi
  - Python implementation
- Python code development
  - Iterative testing
    - Sensors and motors
    - Input and output
  - PyCharm CE
  - Automatic vs. manual
    - Two buttons for manual operation



Initial State (Fastening the Top Shade)

- Our budget became a constraint in the choice of our shading material
  - Larger shading material would have caused the price to increase significantly
- This shade allows removal in inclement conditions

Current State

Evaluating Success

- 85% reduction on the UV scale
- 30% increase of functional space
- Safe and long-term structure
- Successful integration of clean energy
- Minimal ecological impact

SANTA CLARA UNIVERSITY

Acknowledgements

SANTA CLARA UNIVERSITY

Thank You!

Dynamic Solar Shading_Thesis

Final Audit Report 2021-06-11

Created:	2021-06-11
By:	Shane Wibeto (swibeto@scu.edu)
Status:	Signed
Transaction ID:	CBJCHBCAABAAK9Xpy-5jxp94IU9sk4YRqI3L1wELvppt

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