Creating an Automated Green Roof Management System via the Arduino Internet of Things Cloud

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Abstract

An automated green roof management system designed for apartment buildings in Southern California could significantly improve several regional environmental factors. Because Southern California has a dry and windy climate, green roofs can be difficult to maintain and monitor. However, with the implementation of an automated IoT managed system that monitors the surface temperature, light, humidity, pH, turbidity, and water level within the green roof system through an interactive website, green roofs can become easier to maintain and monitor in Southern California.

Introduction

By 2050, almost 68% of the world's population is expected to live in urban city centers. (Harman, 2019). This means that cities, like Los Angeles, will not only need to expand in size, but will also need to become epicenters of renewable development, especially as climate change continues to threaten the globe and increase CO2 emissions. One way that urban planners, architects, and engineers are increasing sustainability in cities is through the implementation of green roofs (**Figure 1**). Green roofs are living roofs that use a variety of materials, plants, and drainage systems to help decrease building energy costs in cities by acting as natural insulation on roofs (Green Roof Technology, 2020). The intricate layers and types of vegetation present allow green roofs to reduce temperatures inside buildings and simultaneously minimize the urban heat island effect, which relates to the idea that a lack of vegetation increases temperatures in cities (Legerton, 2014). The types of vegetation present on green roofs also allow for the removal of harmful toxins, such as nitrous oxide, from the environment (Legerton, 2014).

If green roofs are so beneficial for the environment, why is Los Angeles — a major urban center — lacking them? With Southern California's dry and sometimes windy climate, green roofs can be challenging to maintain **(Figure 2)**. The combination of intense winds and dry seasons makes it difficult to know when to irrigate, cover, or protect green roofs. Additionally, the lack of rainfall in Southern California along with intense summer heat means that these roofs often do not get enough water to properly survive. Although the plants used in the type of green roofs we are proposing are resilient, they still need water and proper care when temperatures go above 90° Fahrenheit (Succulents Box, 2020), which frequently happens during the summer time in Los Angeles. With thousands of residential apartment buildings spread throughout the county, Los Angeles has the potential to become an urban green landscape. If smart Internet of Things (IoT) monitored extensive green roofs are implemented on Los Angeles apartment buildings, Los Angeles will be able to become the next smart city. IoT enabled extensive smart green roofs would not only help green roof owners monitor, maintain, and develop their green roofs remotely, but they would also help minimize the effects of climate change and urban density in Los Angeles.

Figure 1- Green Roof in Greenwich Village

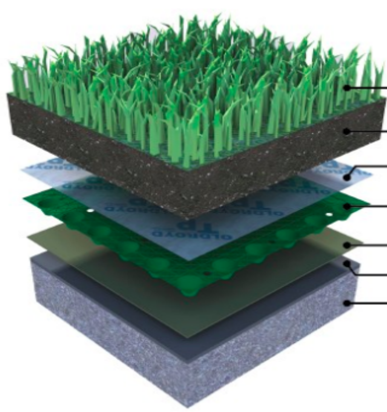
Figure 2- Unmaintained LA Green Roof

1.0 Background

1.1 Green Roof Layers

A typical green roof has seven layers to its basic structure, including a layer for plants/vegetation, a growing medium/soil layer, a filtration layer, a water retention and drainage layer, a root barrier, a waterproof membrane, and the structural support layer/roof (**Figure 3**).

Figure 3 - Green Roof Layers on an Extensive Green Roof.



1.1.1 Vegetation and Growing Media

The vegetation of green roofs depends on the climate where the green roof is located. Sedum species (**Figure 4)**, which thrive in low maintenance environments, are perfect for Southern California's climate (Hui, 2010). Sedums, more commonly known as stonecrops, are a very common and high performing species for low-maintenance green roofs because they do not require a lot of water to survive and thrive in shallow soil (Cascone, 2019). When stonecrops are used for vegetation, the growing medium, or substrate, can be as shallow as 2 centimeters

(Cascone, 2019). Additionally, the optimal soil for green roof vegetation is lightweight, contains enough nutrients and organic materials to keep Sedums alive, and has great water retention, meaning it has a big water holding capacity to allow the plant to absorb a lot of water (Roseli et al., 2014).

Figure 4 - Sedum plants

1.1.2 Filtration and Drainage Layers

Below the layer of soil is a filtration layer, which acts as a barrier between the soil and drainage layers to prevent particles of vegetation and soil from clogging the drainage layer (Cascone, 2019). Along with the growing medium layer, the drainage and water retention layer is crucial for the water management aspect of the green roof system. When sedums are used in the vegetation layer and the green roof location's climate has little rainfall, the water that lands on the green roof is absorbed by the plants. When there is rainfall and the soil has surpassed its saturation point, the drainage and water retention layer drains the excess water (Roseli et al., 2014).

1.1.3 Root Barriers and Roof Safety

The root barrier layer is integrated into the waterproof membrane, protecting it from the vegetative roots that penetrate from the layers above (Cascone, 2019). The root barrier must be a solid, impenetrable surface. The waterproof membrane is the last layer before the roof layer and protects the building from water damage and decay while making the roof weatherproof (Roseli et al., 2014). During construction, the waterproof membrane provides the physical support system for the rest of the other green roof layers. The last layer of the green roof system is the roof itself, which acts as another structural barrier between the components of the green roof and the building.

1.2 Extensive vs Intensive Green Roofs

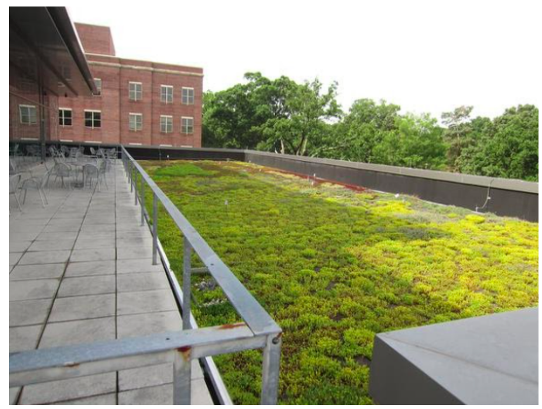
Green roofs fall into two basic categories based on the vegetation and roof bed: extensive and intensive. Each type requires a different maintenance schedule and costs of each will be discussed below.

__1.2.1 Extensive Green Roofs__

Extensive green roofs have a shallow growing medium layer and low species diversity, to decrease the amount of maintenance required (**Figure 5**). They are typically implemented on existing buildings when there are limitations to installation because the building structure does not allow for intense reconstruction (Li, 2008). Extensive green roofs function well in residential areas, on apartment buildings, and on roofs that have small surface areas. The Green Roof Layers diagram (**Figure 3**) represents the layers of an extensive green roof, which is the focus of this project.

Figure 5: Extensive Green Roof Example

Figure 6: Intensive Green Roof Example



__1.2.2 Intensive Green Roofs__

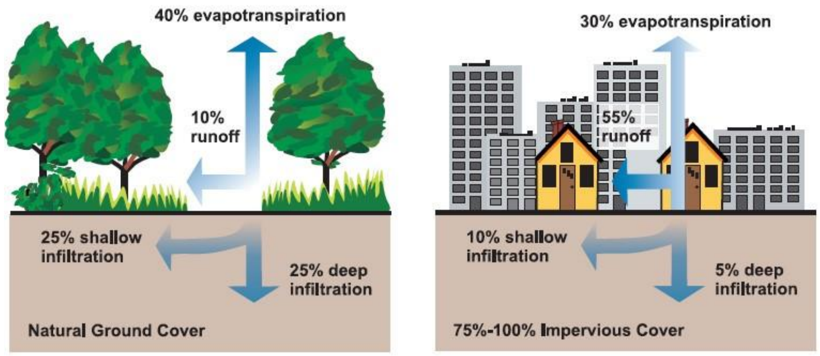
Intensive green roofs have a deep growing medium layer to allow for high species diversity (a wide variety of different plant species), and large vegetation (**Figure 6**), which can include trees and big shrubs (Li, 2008). The layers of intensive green roofs are more difficult to install and require more protective layers with sturdier materials. Intensive green roofs are usually installed during the construction of a new building and they work best on very large buildings and in areas that receive a lot of rainfall (Li, 2008).

1.3 Advantages of Green Roofs.

__1.3.1 Stormwater Runoff.__

In urban areas, like downtown Los Angeles, the stormwater after a rain storm can be moderated by green roofs. Although green roofs cannot control stormwater when there are large and intense storms, they do have the ability to store and use stormwater when the storms are small or moderate (Li, 2008). Because the typical extensive green roof can hold 60% to 100% of stormwater when there is a small or moderate storm (Li, 2008), the amount of stormwater runoff into drainage systems, rivers, and oceans decreases. Although Los Angeles is not known for its rainfall, in the winter months there tends to be a period of moderate storms. In 2019-2020, there was a total of 14.86 inches of rainfall in Downtown Los Angeles (National Weather Service, 2020). Monitoring the amount of stormwater runoff is important because it prevents the groundwater supply in cities from getting polluted. Because cities lack many impervious surfaces (**Figure 7**), stormwater runoff can easily contaminate groundwater if there is not adequate vegetation because as the water runs along the asphalt streets, it picks up all pollutants from cars and garbage (Roseli et al., 2014).

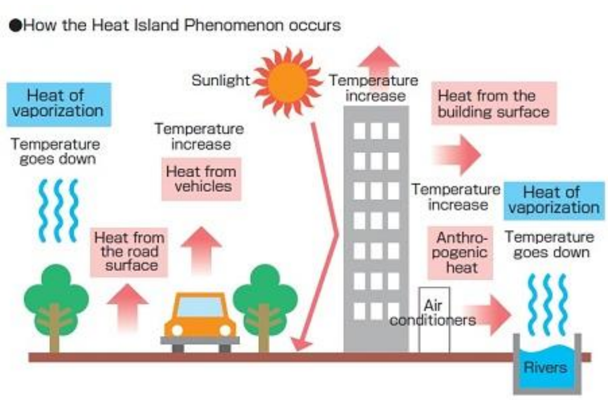
Figure 7 - Natural Ground Cover vs. Impervious Cover



1.3.2 Urban Heat Islands and Air Quality.

An urban heat island, which is an urban area with warm temperatures due to an increase in impenetrable surfaces, is created as cities continue to remove vegetation (EPA, 2020). Normally, vegetation in urban areas helps decrease the heat island effect due to its ability to act as natural insulation (Wong, 2014). However, when cities replace vegetative areas with impervious materials (conventional roof tops, roads, and sidewalks), heat is absorbed into buildings (Kwon, 2017). The heat from these building tops, roads, cars engines, and heating/cooling systems all contribute to increasing the temperature inside of cities (**Figure 8)**.

Figure 8 - Urban Heat Island Effect



As temperatures in cities continue to increase, the demand for air conditioning increases, which uses energy. The implementation of green roofs decreases the need for air conditioning systems because green roofs act as natural insulation (EPA, 2019). In an apartment or house with a regular roof, sunlight is absorbed by the roof causing the heat of the building to increase and in turn causes the demand for air conditioning to increase. But, when an apartment has a green roof, the plants cool the air because they transpire water and there is no more pavement in its place to absorb sunlight, causing the heat of the building to decrease (Leyland, 2020). Additionally, many plants and vegetation, such as those on green roofs can help remove many harmful toxins from the atmosphere through photosynthesis and respiration.

1.4 Finance and Maintenance of Green Roofs.

1.4.1 Expense.

The main reason why green roofs have not become popular on a large scale is the expensive initial cost (**Table 1.1**). Although extensive green roofs are cheaper than intensive green roofs, they still require a significant upfront cost (Sutton, 2018).

Table 1 - Extensive Green Roof Cost Chart

Green Roof Type	**Installation Cost (a one time cost that a green roof owner puts upfront)**	**Maintenance Cost (measured by yearly maintenance fee)**	**Total Cost (Including One-Time Installation and Yearly Maintenance, 1700 square feet)**
Extensive Green Roofs	$9.67 per square foot	$0.58 per square foot (yearly)	$17,425 in an average apartment building (1700 square feet)

1.4.2 Overall Savings

Green roofs can save owners up to $0.23 per square foot of green roof space in a year by decreasing their overall energy energy use by 0.7% (EPA, 2021). This means that if an owner has 1,700 square feet of green roof space (an average LA apartment building), they can save up to $391 per year. More importantly, green roofs will not only help owners save money, but they will also immensely help the environment. As stated in section 3.0, green roofs drastically help reduce city temperatures (Wong, 2014).

1.4.3 Required Maintenance and Care.

Like other vegetative gardens, green roofs require care and maintenance, especially when first implemented. When a green roof is first installed, the plants have to grow and mature, which means that they need to be carefully watered and fertilized until they properly root into the ground (Tanner, 2004). Additionally, each year, green roof owners have to check the nutrition of their soil, remove weeds, and replace dead plants. Even though extensive green roofs require minimal maintenance, green roof owners still need to monitor the plants' health (soil level, nutrients, plant growth, etc.) in order to ensure survival (Green Roof Technology, 2020). Besides their annual maintenance protocols, green roofs also require maintenance after severe weather events. If green roofs are built in areas with hurricanes, tornados, or any other type of severe weather conditions, they must be monitored and checked for damage after each event (Tanner, 2004). In Los Angeles, these extreme weather events include fire, high winds, and long-term droughts. Drainage systems, plant beds, and soil beds must be observed in order to ensure that the green roof is still functional after these natural disasters and not fuel for wildfires.

1.5 Data Measurement

1.5.1 Temperature, Ultraviolet Radiation, Luminance, Soil Moisture Readings on Plant Bed

Data monitoring allows green roof owners to modify and optimize the growing environment. Ultraviolet radiation (specifically UV-B) along with environmental temperatures is monitored in order to ensure that the cell membranes of the plant cells do not get damaged (Climate Policy Watcher, 2021). When pieces of a plant cell are damaged, photosynthesis cannot take place and the plant dies. Additionally, luminance (the intensity of light emitted from the sun) will be monitored so that the plants can properly perform photosynthesis (a process which requires light) and so that users can be alerted when sunlight levels are intense, as irrigation levels should be more closely monitored during periods of intense and hot sunlight (Vierling, 2017). Lastly, soil moisture is monitored in order to make sure that the plants themselves are being given enough water to survive. If the soil is not moist enough, then the plants will run out of a water supply and consequently be unable to perform photosynthesis (Climate Policy Watcher, 2021).

1.5.2 Turbidity and pH Within the Irrigation System

Turbidity and pH within the green roof's irrigation system is monitored in order to ensure that the water being collected from the green roof is safe and healthy for plants.
Turbidity is a relative measure of water clarity, which means that the dirtier the water, the higher the turbidity (USGS, 2020). By measuring turbidity in this system, the water collected can be checked for soil and particle contamination. If the water is not checked for contaminants, it could damage the plants in the future. Additionally, pH is used to determine whether water is basic or acidic (USGS, 2020). If the water is too acidic or too basic, then the water is unhealthy for the plants.

1.6 Literature Review

1.6.1 Science Behind Green Roofs

Green roofs help alleviate air pollution, the urban heat island effect, and energy usage within cities. The large surface area present on green roofs allows for optimal plant coverage/implementation in major urban centers. The more plants there are in cities, the more pollutants are absorbed, as air pollutant absorption is done by any vegetation (Hewitt, 2019). When these pollutants are absorbed, greenhouse gas and ozone levels decrease, and the vegetation on top of the green itself produces oxygen. Additionally, the large surface area and thick floor of a green roof help reduce the urban heat island effect and noise pollution. The dense layers of a green roof reflect sound, which means that noise does not travel as easily through building walls. The plants on a green roof also act as a natural insulative layer that reduces temperatures inside of buildings and saves energy costs. The plants on the green roof absorb the sunlight and through photosynthesis turn much of that sunlight into energy for the plant itself. Green roofs not only look good, but the science behind them promotes sustainable cities.

1.6.2 Green Roof Automation Market and Competition

Green roof automation is a growing industry that is expanding as green roofs become more popular in urban areas. Many companies have started to make an impact in the field as they strive to make green roofs more accessible for everyone. Two examples of companies that are working in this growing industry are NexSens Technology and BigLadder Software. .

NexSens Technology, a company in Ohio that specializes in the design and manufacture of environmental measurement systems, has created a green roof monitoring system that ensures green roofs live up to their promise of helping the environment. This green roof monitoring system focuses on monitoring stormwater collection in extensive green roofs. It has various soil moisture, surface temperature, and precipitation sensors that help green roof owners estimate the amount of irrigation that is needed to support their vegetation (NexSens). The roof system also monitors a host of other factors, such as plant-available moisture, solar radiation, micro-climate variables, and changes in vegetation coverage, in order to ensure that the roof properly functions. Data scientists at the company then use all of this data that is collected to monitor erratic weather, precipitation, irrigation systems, and storm management (NexSens, 2020). The system also has a runoff vessel that collects stormwater in order to measure the water level and precipitation patterns in the area. Although NexSens technology has a lot to offer green roof owners, it solely focuses on storm and irrigation management in green roofs. The system fails to provide users with an easy way to monitor their green roof on a daily basis. The system also has a great monitoring system for storm management; however, in places like Los Angeles, where storms seldom occur, the system described above would not be of much use.

Additionally, BigLadder Software, a Denver-based software company that focuses on providing software for the building energy modeling industry, has also created another type of green roof management software that helps green roof owners become aware of the possible energy savings that their green roof has to offer. BigLadder Software's system works by using a computational model of the heat transfer process on vegetated roofs to calculate the estimated energy savings a green roof would have on a building (BigLadder, 2020). It uses various evapotranspiration, plant canopy, heat conduction, and long/short wave radiation exchange equations along with various user-specified factors, such as roof depth, height, growing media depth, thermal properties, plant height, etc., in order to give users an estimate on the impact that their green roof would have on the environment. Although BigLadder's software system is not a live-feed, automated data collection system, it is a tool that can help assess the impact that a green roof would have in a specific area. BigLadder Software's system highlights the fact that both potential green roof owners and current green roof owners want to know how much energy their green roof system is really saving. This kind of energy monitoring model that BigLadder Software has can be implemented into a live monitoring system in order to help users figure out how much energy their roof is saving them on a daily, monthly, or yearly basis.

Currently missing in the green roof monitoring market are smaller, user-friendly green roof management systems that focus on the green roof as a whole and not just irrigation, energy, or plant health. Additionally, as stated above, most of the current systems focus on water management on green roofs. Although water management is important, in Los Angeles, it is more important to monitor the roof's progress during droughts and other dry seasons. The lack of a system that takes Los Angeles-specific environmental factors, such as high temperature, low precipitation, low humidity, and intense sunlight, leaves open space in the industry for a Southern California-based system.

2.0 Methods

2.1 Green Roof Testbed

A testbed for an extensive green roof (**Figure 8)** was constructed for this project. The testbed consists of sedum plants and a full complement of environmental sensors that will be used for collecting data on the light, temperature, UV, pH, turbidity, soil moisture and water level of the prototype system.

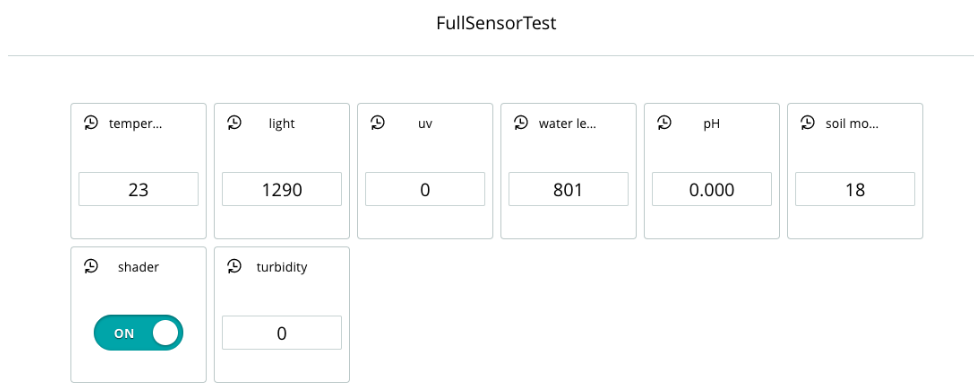
Figure 8 - Photo of Green Roof Prototype

2.1.1 Sensors

An analog pH sensor, Gravity analog turbidity sensor, Arduino Capacitive soil moisture sensor, Arduino water level sensor, and the Arduino MKR Env Shield sensors (temperature, uv, light) were used. These sensors are all connected to the Arduino IoT Cloud via the Arduino MKR 1010 Wifi Board (**Figure 9**).

Figure 9 - IoT Dashboard

2.1.2



Construction of Physical Test Bed & Water Capture System

An open-top table testbed was constructed as shown in dimensional drawings (**Figures 10-14**). Plants and construction materials were chosen to simulate the conditions for a typical extensive green roof installation. The sensor suite hardware was placed on an adjacent shelf for ease access during testing. The water capture system *(***Figure 10, 11***)* was installed directly underneath the open-top table.

Figure 10 - Dimensional Sketch of Full Green Roof Testbed

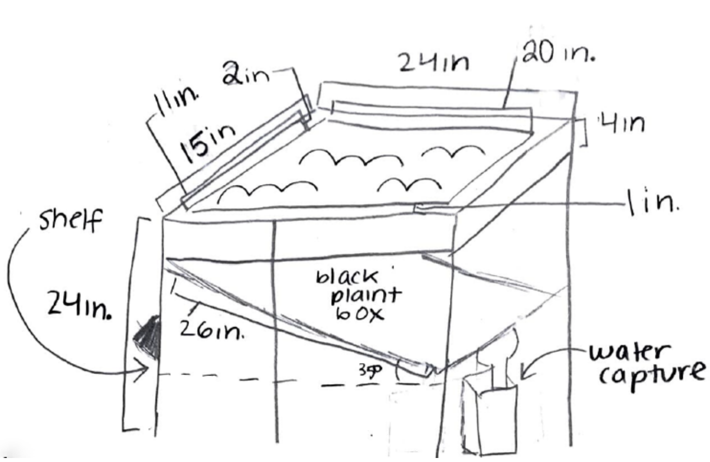


Figure 11- Side View of Testbed

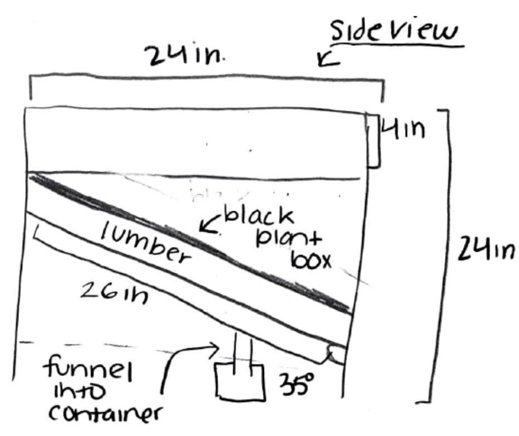


Figure 12 - Sensor Shelf

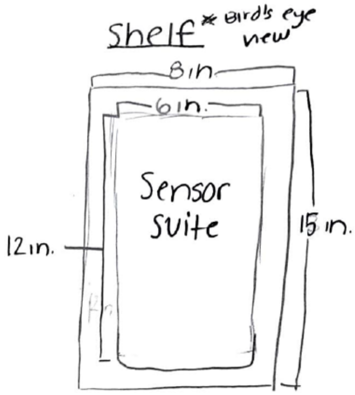


Figure 13 - Plant Container

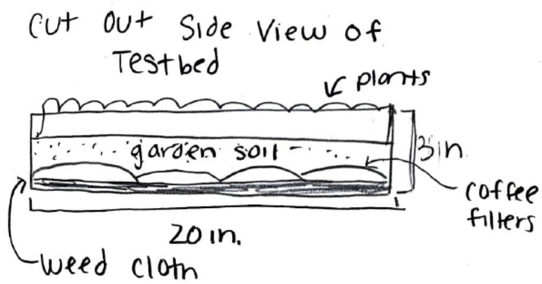
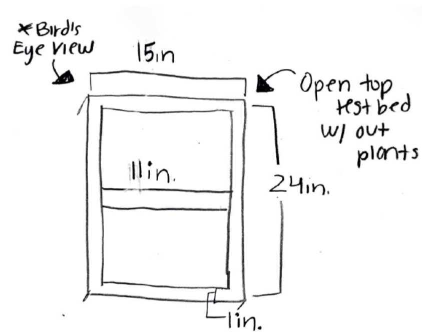


Figure 14 - Open-Top Table



2.1.3 Construction of Shader System

A sun shader system (designed to shield the plants from intense sunlight and high winds), was installed on the testbed (**Figure 15, 16, 17, 18**) to demonstrate the retractor function.

Figure 15- Installed Shader System Half Open

Figure 16- Installed Shader System Closed

For this system, a single motor attached to a PVC pipe will drive the shader forward and backward. This is due to the nature of the string-pulley system seen in **Figures 17, 18**.

Figure 17- Shader System Side View (w/ Strings)

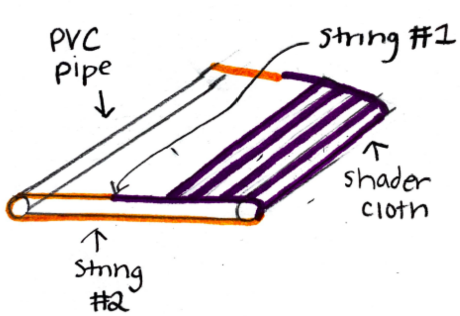
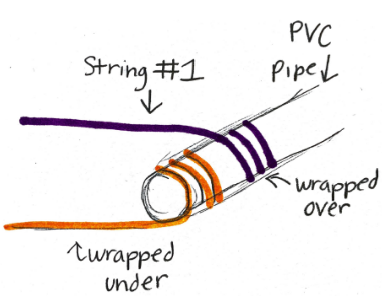


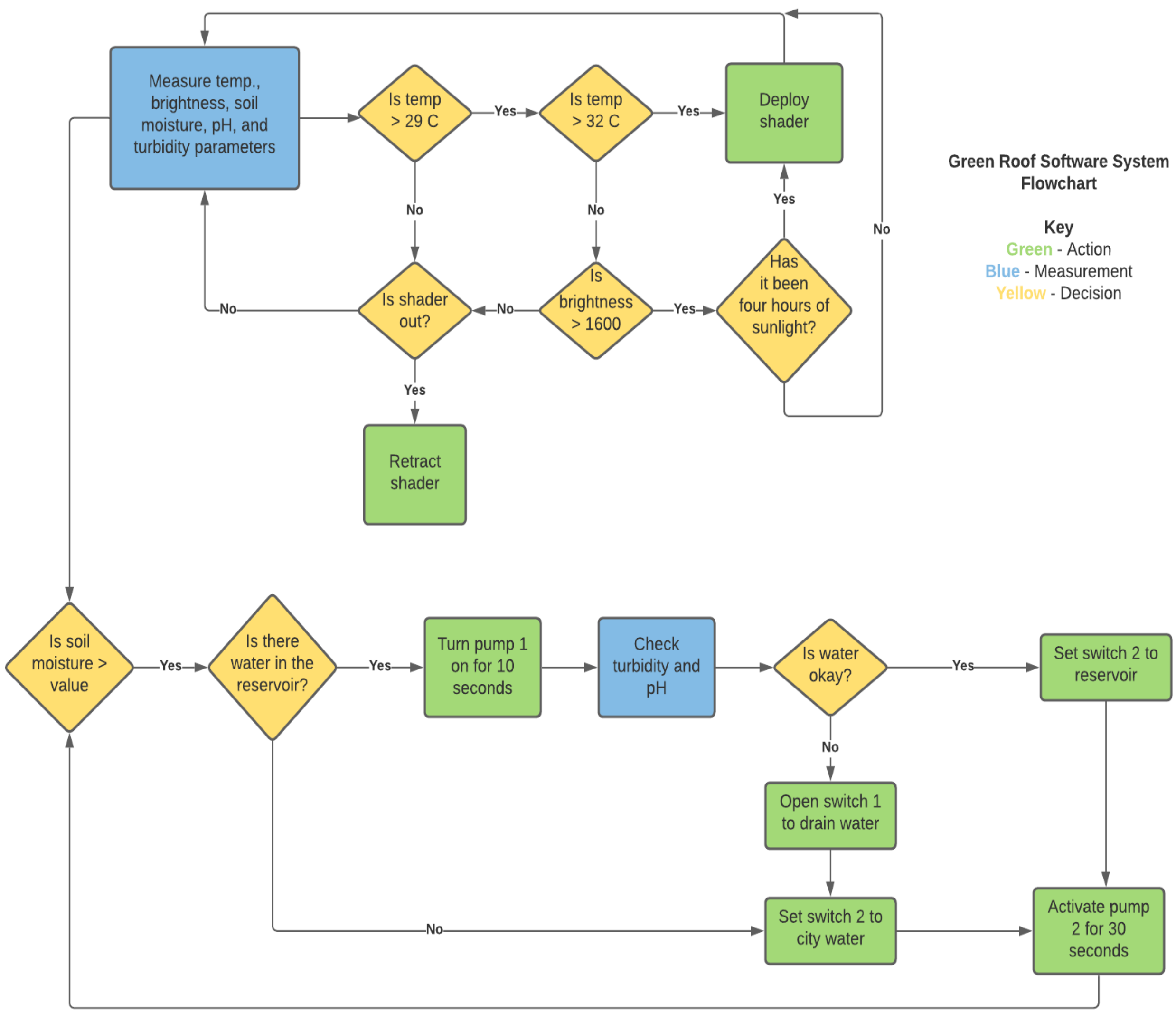
Figure 18 - String System Zoom-In



2.2 Automated Control Process

The Automation Control Unit manages maintenance through the recording and publishing of relevant sensor data as well as automatically managing the sun/wind shader deployment and the water capture system functions. The automation process is shown in **Figure 19.**

Figure 19 - Green Roof Software Flowchart



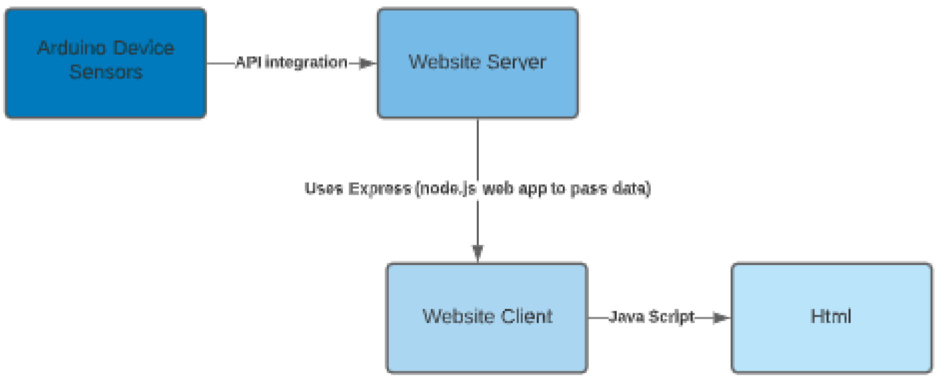
2.3 Creation of Website

A companion website was created to serve as the public interface to all sensor data. For this prototype, the free service glitch.com was used to provide access to both server and client side programming.

2.3.1 Pulling Data from Arduino IoT Cloud

As seen on the flowchart in **Figure 20**, there are three main components to get data from an arduino sensor to html. The data has to be transferred from the sensor to the website server using API integration, then from the website client server to the website client using express, and then finally from the website client into html using javascript.

Figure 20: Flowchart of Data Transfer onto Website



Using an Arduino IoT Cloud API integration resource document (**s**ee appendices for link), an API call named propertiesV2List was used. Using this call, the metadata from each sensor, as seen in **Figure 21,** was available to the web server.

Figure 21: Property metadata from Water-level sensor


```
[ 'id', '22724932-6d7a-4f33-9fed-9134a3de4f90' ],
[ 'name', 'waterLevel' ],
[ 'permission', 'READ_WRITE' ],
[ 'thing_id', 'c9f99635-df0d-4a5d-af69-d73ad974c75c' ],
[ 'type', 'INT' ],
[ 'update_strategy', 'ON_CHANGE' ],
[ 'created_at', 2021-01-14T20:04:47.438Z ],
[ 'last_value', 757 ],
[ 'persist', true ],
[ 'tag', 5 ],
[ 'update_parameter', 1 ],
[ 'updated_at', 2021-01-14T20:04:47.438Z ],
[ 'value_updated_at', 2021-05-10T17:21:22.563Z ],
[ 'variable_name', 'waterLevel' ]
```

Data values from the *name* and *last_value* properties are passed to the web server. Full code documentation is available in the appendices.

2.3.2 Website Structure

The ultimate goal of the website is to help popularize the use of green roofs in cities. In order to achieve this, the basic website layout of commercial products was used. This includes the key elements for a website: a catchy product name, easy navigation tools, and a stylish, simple logo.

Along with these key requirements, the following technical requirements were set: a data table with the arduino sensor data, icons for the water capture system and shader/wind shader, resources pages with green roof and sustainability information, and basic information about the concept of Cover.

2.4 Green Roof Component Testing

2.4.1 Water Absorption Test

A water absorption test was conducted to ensure that green roofs do in fact reduce stormwater runoff in cities by absorbing rain water. For this test, various amounts of rain water (0.1 in., 0.2 in., 0.5 in., 1 inch, 2 inches, 3 inches) were sprinkled onto the green roof. The water that the green roof did not absorb then flowed into the water capture system container. This amount of water was then recorded and compared to the original amount of water.

2.4.2 Temperature Reduction Test

The temperature/insulation test ensured that the green roof did in fact act as natural insulation on buildings by reducing the temperature on hot days. For this test, two temperature sensors were used. One sensor was placed directly on the testbed (in the midst of the plants) and the other was placed directly on a piece of ceramic roof tile. The temperatures were then checked and recorded every hour from 10 am to 7 pm throughout the day.

2.4.3 Shader Material Test

A light sensor and temperature sensor were placed directly in the sun for five minutes, then directly under the shader for five minutes, and then directly back in the sun for five minutes. In each five minute interval, the temperature and light readings from the sensors were recorded.

2.4.4 Water Reservoir Level Test (Automation System)

In order to determine if the water reservoir is full of water, a water level sensor will be placed inside the water container. If the sensor detects that there is water in the reservoir, then water will be pumped into the pH/turbidity testing container. If there is no water in the reservoir, then the irrigation system will be switched to the city water supply system.

2.4.5 Water Reservoir pH/Turbidity Test

In order to determine if the pH/turbidity of the reservoir is okay, water will be pumped into a separate pH/turbidity testing container. The sensors will then check the values to see if certain conditions are met. If the water is not okay, then the container will dump the water out into a city sewer system; however, if the water is okay, then the irrigation system will re-use it.

2.4.6 Software Validation

In order to ensure that the green roof system's automation software works correctly, a message was encoded in the console log to reveal itself when the conditions to deploy/retract the shader were met.

2.5.6 Website Validation

A survey was sent out to homeowners, renters, building owners, and high school students to get feedback about the website and the overall project idea. A series of questions were asked about the website layout/functionality and product aspect of Cover.

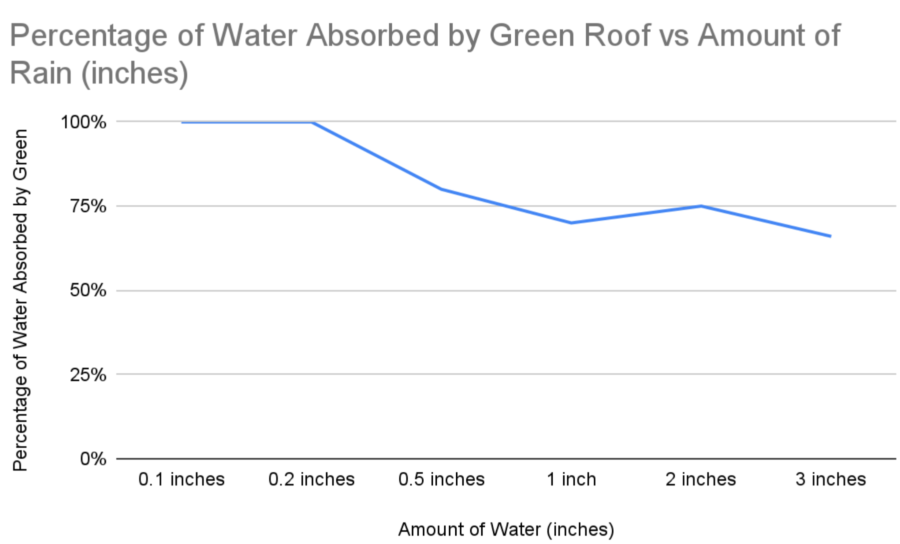
3.0 Results

3.1 Testbed Component Test Results

3.1.1 Stormwater Results

During testing it was found that green roofs absorb around 75% of stormwater in Los Angeles (**Figure 22**). This means that a large percentage of stormwater runoff in LA could be collected and reused rather than discarded and polluted.

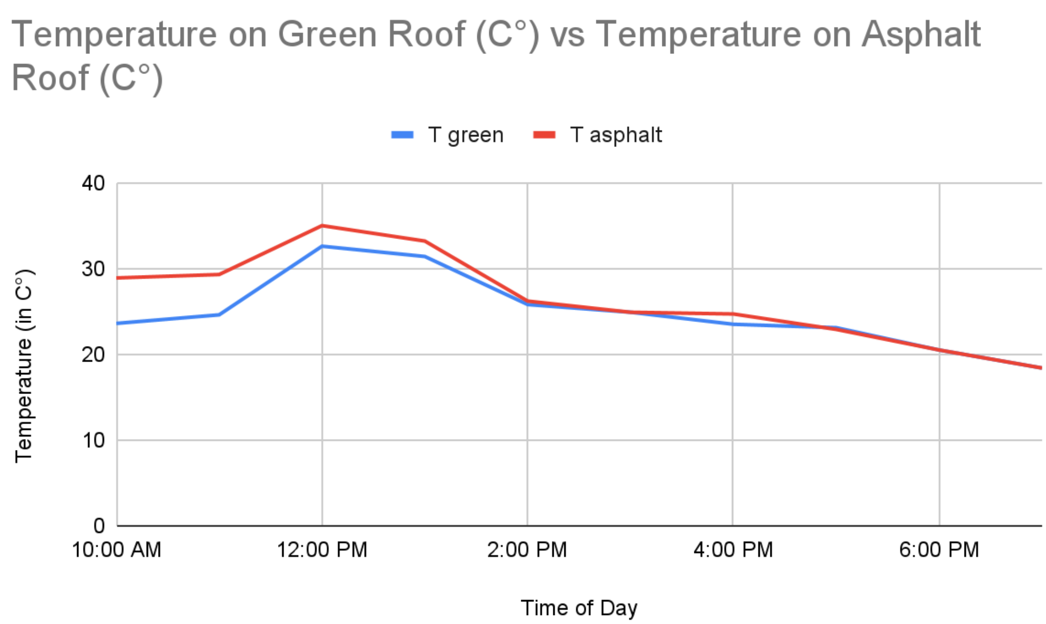
Figure 22 - Stormwater Validation Results Graph



3.1.2 Temperature Results

It was found that green roofs act as natural insulation on top of buildings. As seen in **Figure 23**, the temperature on the green roof is lower when it is warm outside, as the blue line is consistently lower than the red line in high temperatures.

Figure 23 - Temperature Validation Test Results



3.1.3 Shader Results

The shader system was also found to be effective at shielding the plants by reducing environmental temperatures by 1° C and blocking 86% of intense sunlight (see **Figures 28, 29** in appendices). This means that the plants would be shielded from harmful UV radiation.

3.2 Automated Control Process Results

Until the sensors, shader system, and water capture system are installed and fully functional, the automation process is managed through console log messages. When a sensor records data, a message is sent to the console log if the shader is supposed to be deployed or retracted (see **Figure 19** for details regarding the software flow process).

3.3 Website

3.3.1 Website Details and Outline

Project Cover is named to highlight the most important physical part of the project: the wind and sun shader. A simple, memorable logo is the key visual identity for the website (**Figure 24**).

Figure 24 - Cover Logo

The data page includes a real time data table with the name of each sensor and its last value so users can monitor in real time the progress of their green roof (**Figure 25**). Also on the data page, users can view the status of their shader and water capture system through displayed icons, one for each possible sun and wind shader status. . an icon key at the bottom of the data page serves as an icon legend (**Figure 26**). The water capture system follows the same structure (**Figure 27**). The icons were created as a fun, new way for users to check in on their green roofs.

Figure 25: Real-time sensor data displayed on website

click here to update data!

Sensor Name	Last Value
UV	0
Light	1580
Temperature	43
Water Level	979
pH	0
Turbidity	0
Soil Moisture	18

Figure 26: Sun/Wind Shader Icons

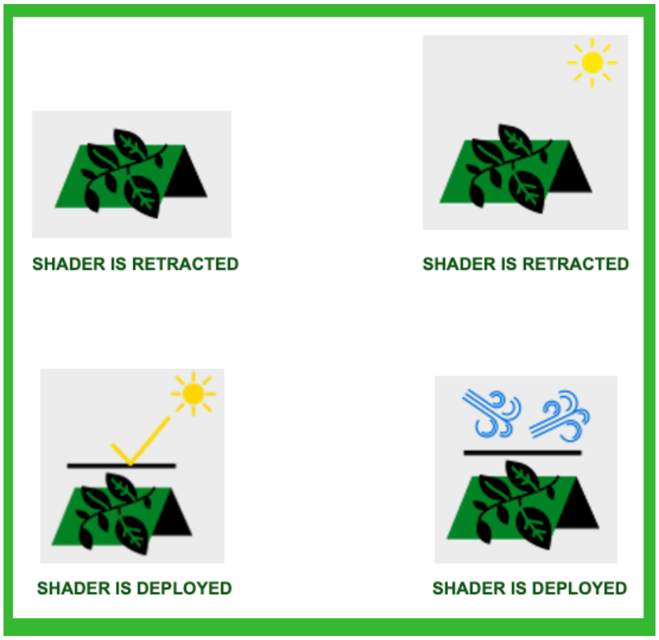


Figure 27: Water Capture System Icons

3.3.2 Website Validation Results

A survey with a series of questions about both the overall concept of Cover and functionality of Cover's website was sent out to homeowners, renters, building owners, and high school students. A total of 51 people filled out the survey, majority being students and the second majority being homeowners. A series of questions about the website navigation were answered by all 51 users with 96% of responses showing a positive experience, suggesting the website is effective at communicating Cover's goal and purpose.

4.0 Discussion

4.1 Testbed

The testbed's performance in all of these validation tests demonstrate that green roofs increase the sustainability of urban areas by acting as natural insulation for buildings and absorbing stormwater runoff. Additionally, the software's ability to retract/deploy the shader during the proper conditions confirms that Cover extends plant life protocols by preventing scorch / wind damage. This means that Cover will not only increase sustainability in urban communities, but also ease the maintenance aspect of green roof ownership.

4.2 Website

Along with the series of questions asked about website navigation, survey takers were also given the opportunity to give specific feedback about their experience on the website. And while most of these responses were positive and straightforward, some offered helpful feedback regarding website layout. Since many of the survey takers were homeowners, the assumption was made that many of them were middle aged. Many were confused about layout and very basic technical maneuvers which gave great feedback about simplifying the technology to be more basic and user friendly.

When looking at specific feedback, the responses from high school students were useful for further exploration and improvement. Since technology is heavily ingrained in the lives of Generation Z, a lot of feedback was received regarding how to make the layout, color schemes, and other specific website design elements even better. Having the perspective of the younger generation is helpful when working on a project focused on the future of our world.

4.3 Further Exploration

4.3.1 Further Technical Exploration

Enhancements of Cover's shader system are needed for full automation. The current prototype consists of a motorless shader that is not integrated with the automatic software system. The addition of a motor-driven shader would be recommended. Additionally, the water capture system sensors should be installed and tested, with connection to automated pump and source switching hardware as a final step.

4.3.2 Further Exploration Marketing

Based on the results from the website validation survey sent out to homeowners, renters, building owners, and high school students, it was concluded that the website was effective at relaying the mission of Cover and met the basic requirements for easy navigation. Although most of the feedback from the survey was positive, there is always work to be done to make the website even better. In order to cater to a larger audience, website navigation would be altered. Creating even more basic maneuvers to the website would allow older generations to be involved, including more specific tabs and descriptions of how the website itself works.

One main marketing strategy that could be utilized in the future is making the website compatible with mobile devices. As of right now, users can only access their personalized website via a computer through chrome, but opening up the possibilities of where a user can view their data would help popularize Cover even further. The idea of having an application on one's mobile device is very appealing and has become the new norm.

5.0 Conclusion

The goal of Cover was to popularize the use of green roofs in Los Angeles through an automated system and to provide green roof owners an easy way to monitor and maintain their green roofs. Cover's two components include a testbed green roof with a series of environmental sensors, a sun/wind shader, and a water capture system, and a companion website to display all sensor data remotely. After the completion of prototyping, a series of tests were conducted and a survey was sent out to help verify the validity of Cover's concept and the prototypes. The prototypes achieved the basic goals required for both a green roof and website. Also, using these results opens up the ideas for further exploration.

6.0 References

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7.0 Appendices

Links to Additional Information Referenced:

Automation Software: Testbed Final Automation Code
API Integration Resource Document: API Integration Resource Document
Website Code: Website Final Code
Website Navigation video: Website Navigation Final Video
Website Link: https://cover-green-roofs.glitch.me/

Figure 28: Shader Validation Temperature Test

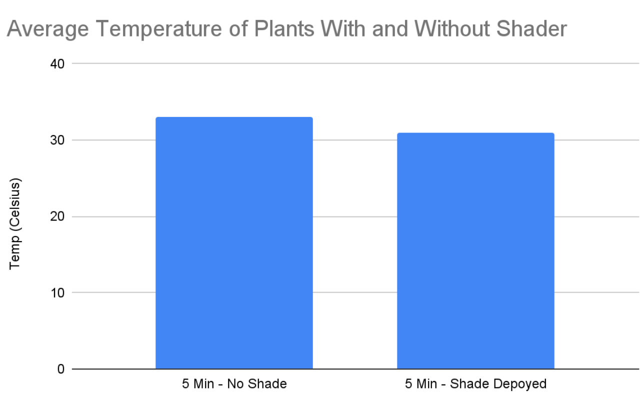

Figure 29: Shader Validation Light Test

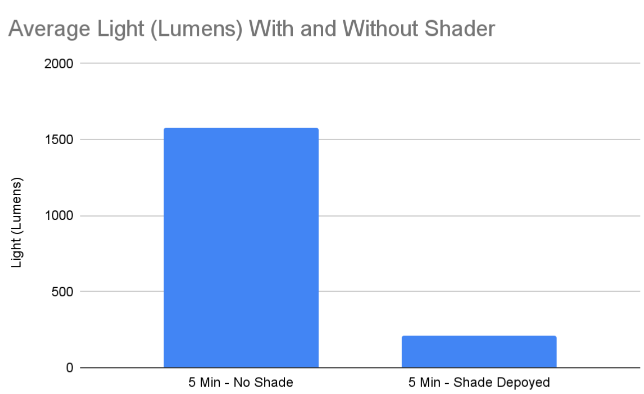

Figure 30: Survey Result: Appeal of Cover Question

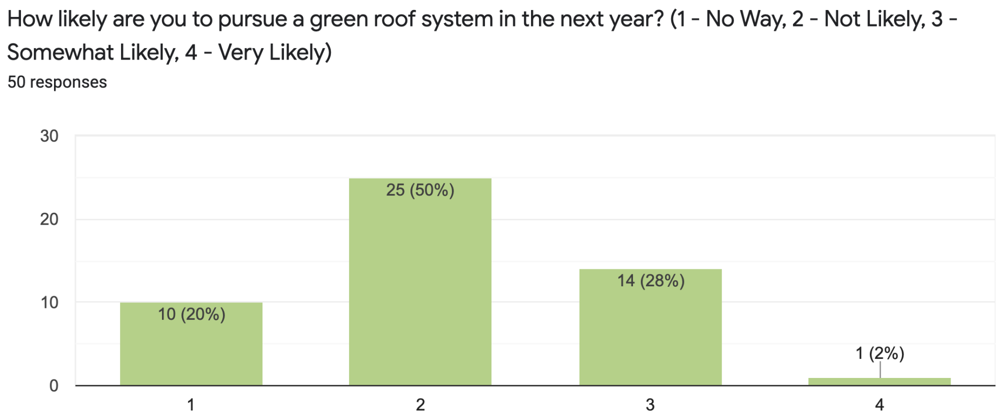

Figure 31: Survey Result: Groups of People Pie Chart

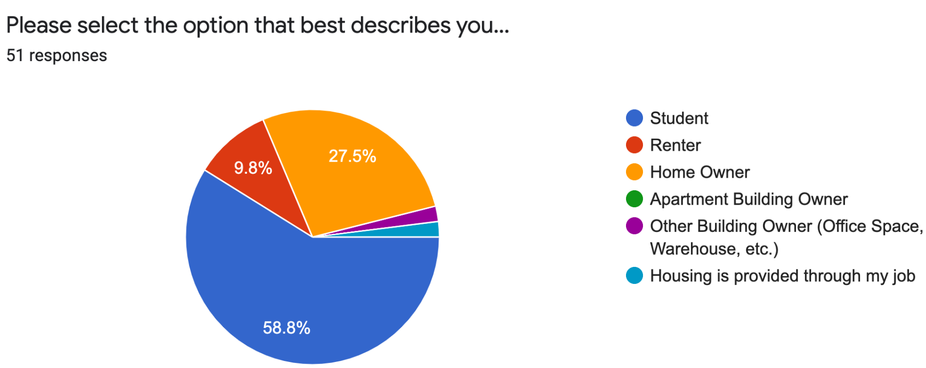

Figure 32: Survey Result: Current Green Roof Market Question

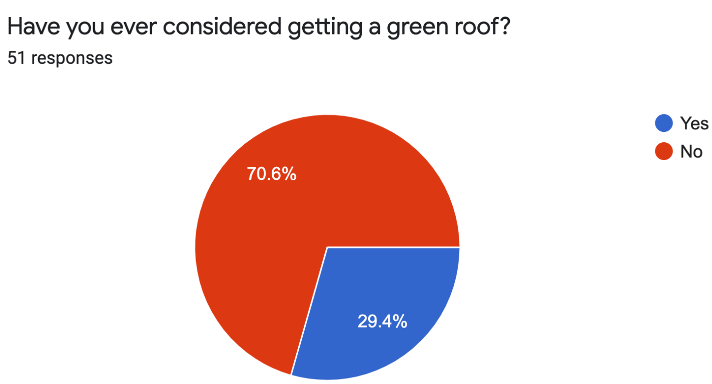

Figure 33: Survey Result: Additional Sensor Suggestions / Questions

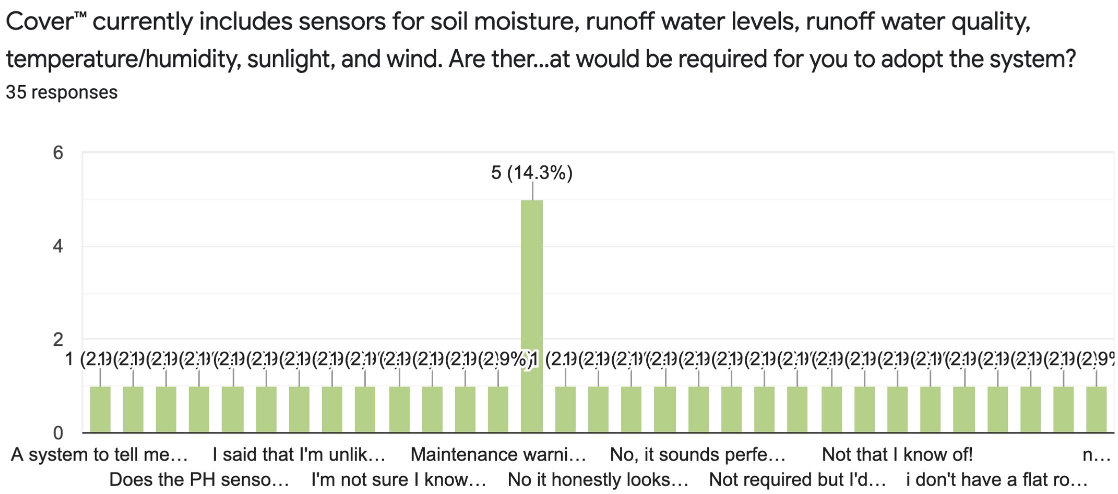

Figure 34: Survey Result: Appeal of Smart Monitoring System Add-On to Green Roofs