Yarilo: A Green Roof Monitoring and Control System

Chance Perekslis, Samuel Taishoff, Max Edminster

Department of Engineering, Trinity College, Hartford, CT 06106

Faculty Advisor: John Mertens

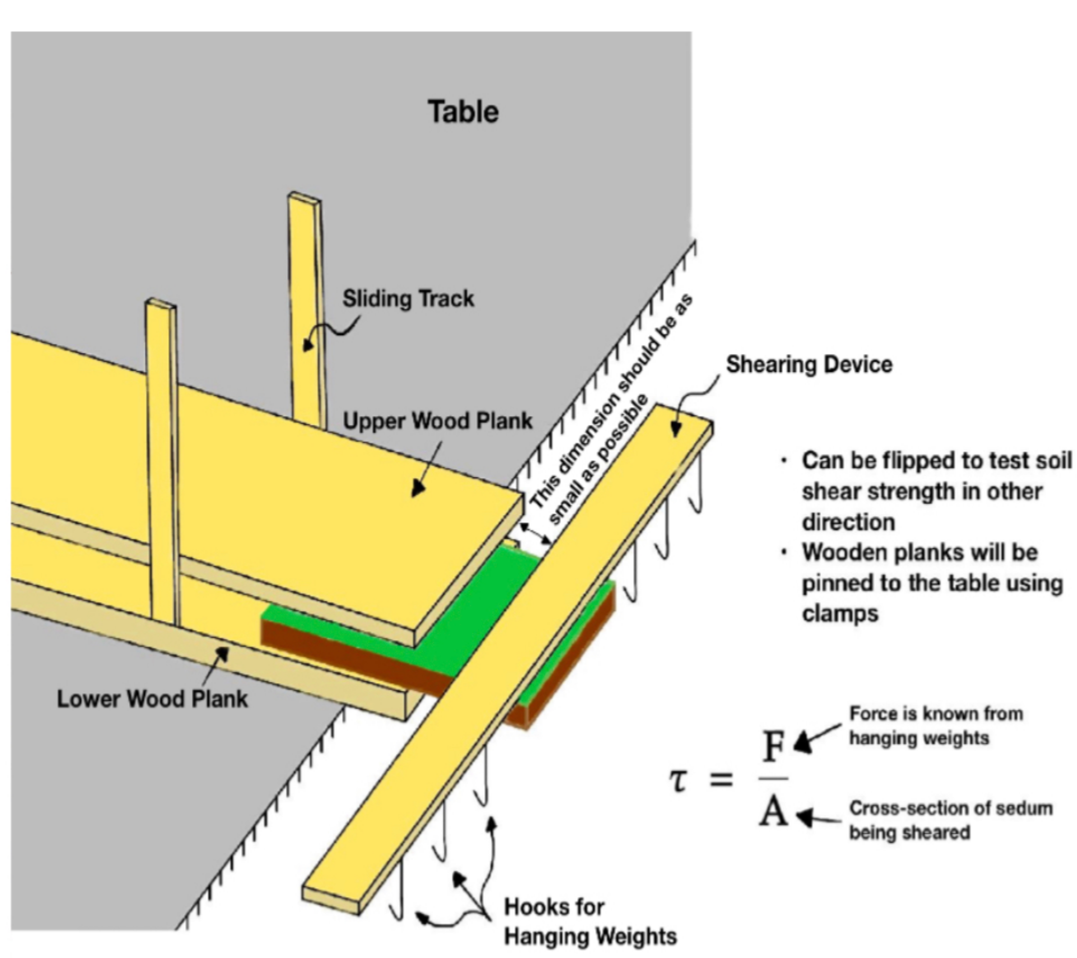
Abstract

This project sought to address limiting factors in the construction of green roofs at slopes beyond the global recommendation of 40° max. The two primary limiting factors identified through research are soil shear/soil slumping and water retention. To address these issues, a monitoring and control system, referred to as Yarilo for brevity, has been developed. The monitoring portion of Yarilo relies upon an Arduino Uno and a series of moisture, soil temperature, and UV sensors as well as an LCD screen for displaying live data. Yarilo will collect data from the growing medium and utilize the received information to appropriately engage its control aspect. The control portion will feature a drip feed irrigation system which can maintain moisture levels in the growing medium conducive to the ideal growth of the green roof plants. This irrigation system will serve a dual purpose in providing resistance to shear forces within the growing medium through a series of retaining spikes. Furthermore, the irrigation system will also feature a water recollection system which will harvest rain and reuse water in a sustainable fashion.

Soil Shear Strength Testing

- Soil slumping is a common type of failure for green roofs at increased angles
- This is due to increased shear stresses between the layers of soil
- We've developed a test to measure the shear strength of soil
- Shear tests were conducted in both the vertical and horizontal directions of the sedum sample
- Shear tests were done for different moisture content values and soil densities
- Values for the shear stress are calculated from $\tau = F/A$
- Issue with many trials was sedum was failing due to bending stress
- Table below shows results for the samples that failed under shear loading

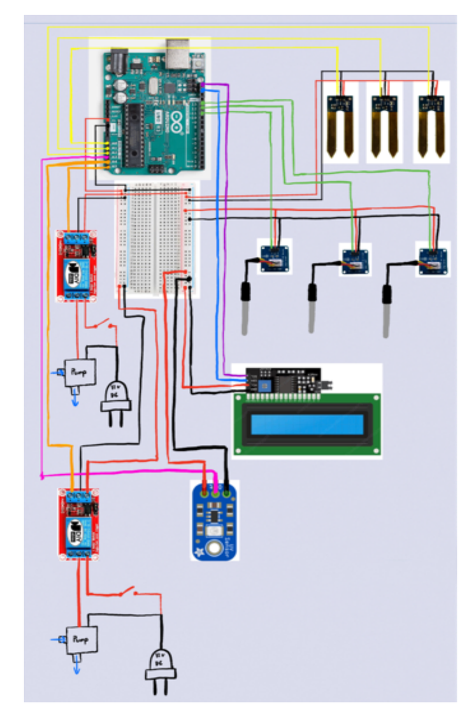
Trial #	Type of Test	Shear Stress (kPa)
1	Horizontal	12.018
2	Horizontal	11.182
3	Horizontal	8.673
4	Vertical	10.346
5	Horizontal (100 mL water added)	7.837
6	Vertical (100 mL water added)	10.346



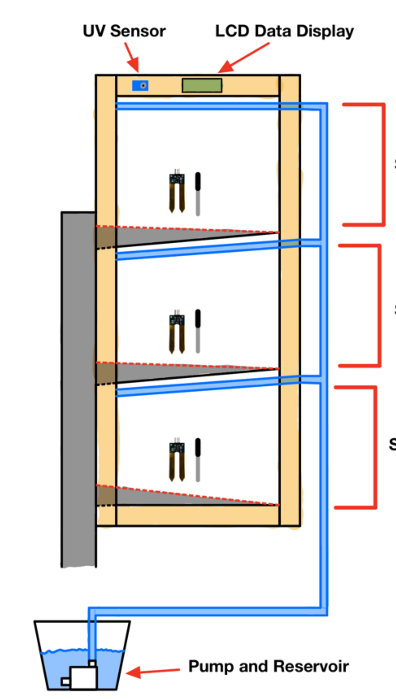
Schematic of Soil Shear Test

Yarilo Control System

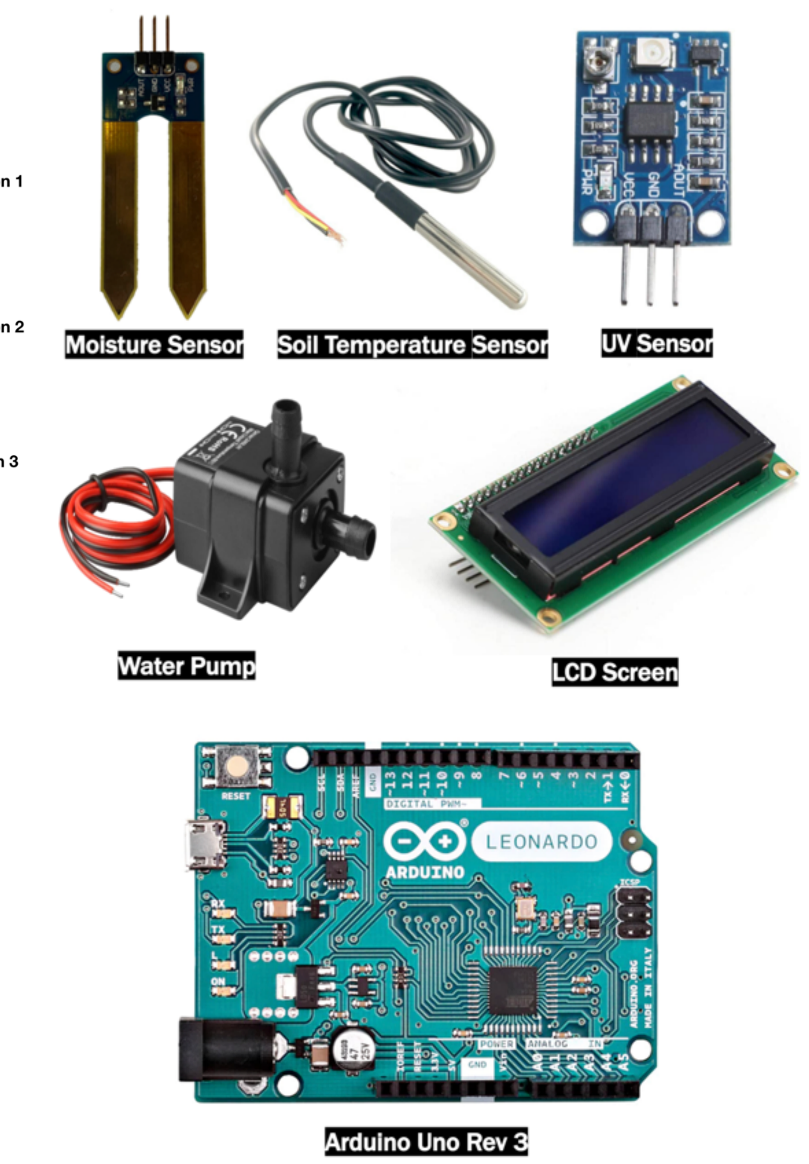
For the monitoring and control system, Yarilo, we use a variety of sensors. We utilize a combination of an Arduino Uno Rev 3 with several moisture, temperature, and UV sensors along with an LCD screen to display live data and a 12V DC pump to distribute water throughout the VAT. For Yarilo, we want to have the most accurate results for measuring moisture content for a range of conditions. Moisture sensors work by measuring the resistance level between its two metal probes. We found that even when two soil samples that have the same amount of water content are analyzed, the sensor may give different readings due to the soil samples having different conductivity levels. Through research and testing, we determined that the two main contributors to changing soil conductivity include soil temperature and soil density. An increase in a soils density causes the contact between soil particles to increase resulting in less resistance as the soil is less porous. An increase in soil temperature affects the viscosity of the water within the soil. The increased viscosity causes an increase in ionic activity. We were able to use data we collected to adjust the Yarilo system to be able to account for temperature and density changes. Temperature and moisture sensors will work in tandem to give the system accurate soil moisture measurements in order to activate the water distribution system when needed.

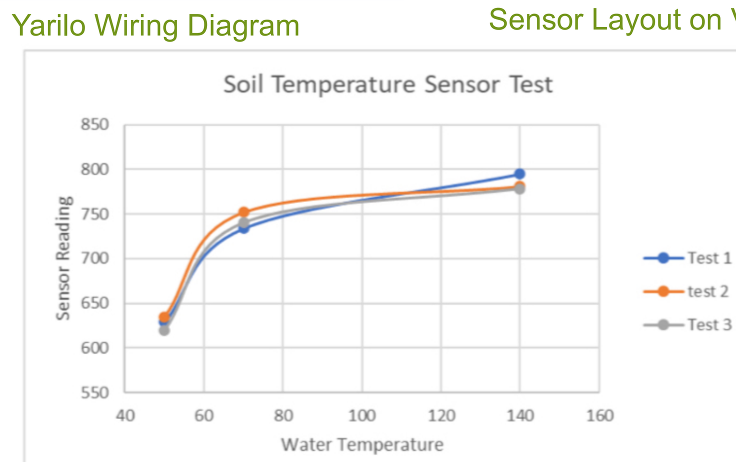


Yarilo Wiring Diagram

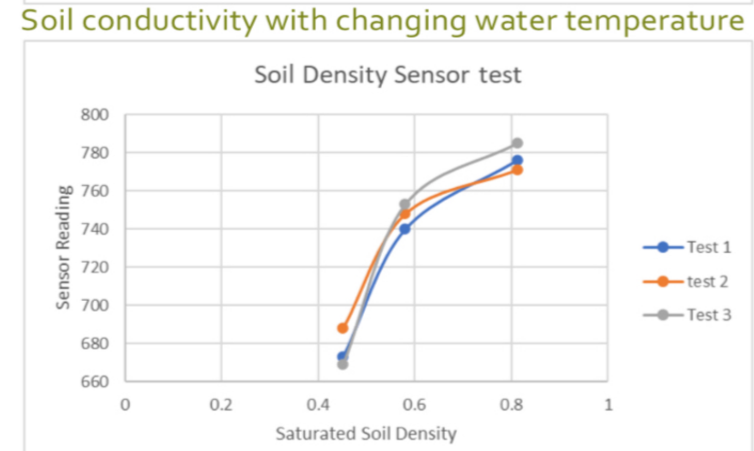


Sensor Layout on VAT

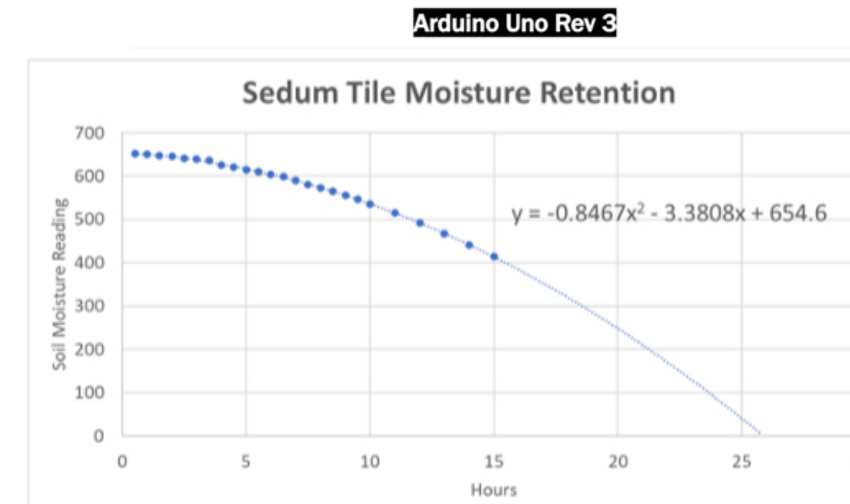




Soil conductivity with changing water temperature



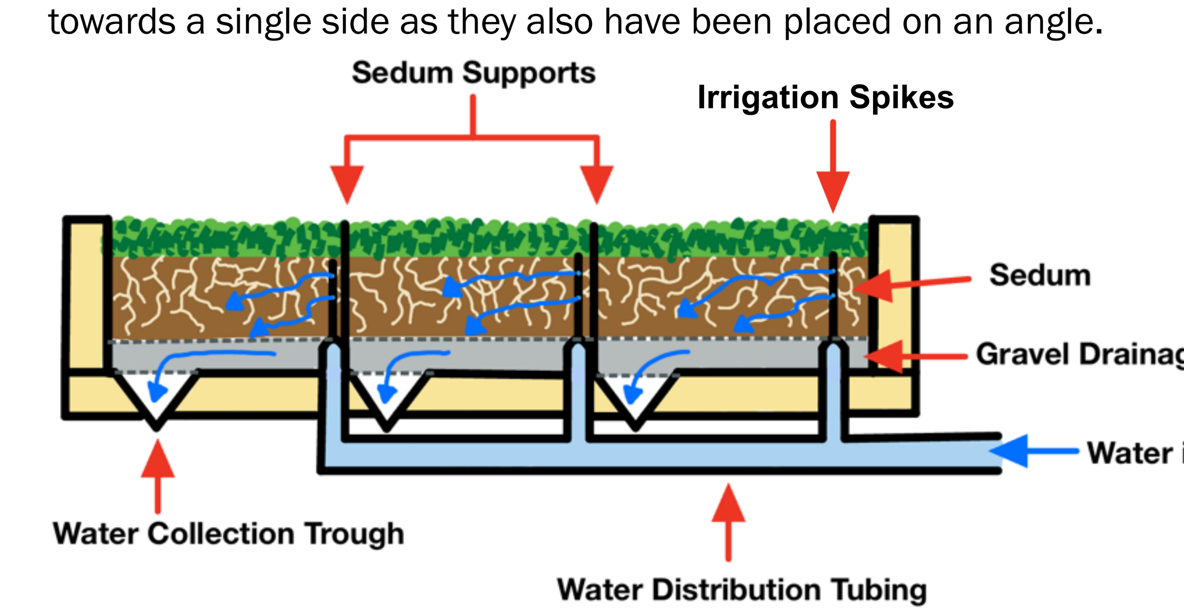
Soil conductivity with changing soil density



Sedum tile moisture retention test with 15 hours of data

Variable Angle Tray (VAT)

We have designed a small scale simulated version of our green roof design that we call the VAT. This tray allows us to set the sedum tiles to several different angles using a hinge system allowing us to test and experiment how the sedum and our control system reacts at different angles. Sedum requires well draining soil so a major component of the VAT is the water recollection system as well as the water distribution system. While it is important that the excess water in the sedum soil is able to drain quickly, sedum still requires consistent watering in order to survive. In the system, water is distributed to the top of three sections of the VAT by a pump that is in a water reservoir. Water is brought up and distributed into the sedum soil by silicon tubing and irrigation spikes that we have created to distribute water evenly throughout the soil. For the recollection of water, water must first drain through the soil before it reaches a gravel drainage layer. The water continues to flow down to the bottom of each section where it meets water troughs that have been designed on an angle to ensure the path of the water goes towards one side to be rerouted back to the water reservoir. The three sections of sedum are also separated by sedum supports that isolate each section from one another. This creates more consistency in the monitoring and distribution of water and moisture levels. These sedum supports add structural support while also acting as an additional barrier to help guide water towards a single side as they also have been placed on an angle.



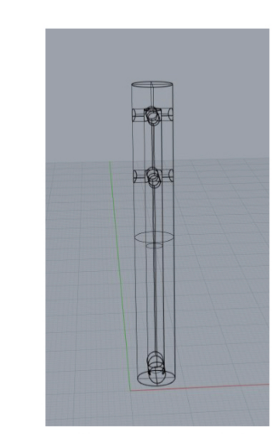
What is Sedum?

For the plants being considered for green roofs, there is an incredibly diverse variety of plants suitable for green roofs. These plants range from grasses to flowers, but the research shows that the plants which are most often considered for green roofs, particularly steep ones, are the very hardy succulents such as sedum. Sedum is a large genus of flowering plants in the Crassulaceae family. The Crassulaceae family is affectionately known by gardeners as Stonecrop because only rocks are more resilient than them. Of all the genera of the Crassulaceae family, sedum has the largest number of species, originally 600 but reduced in the modern age to about 420-470. Sedum is the most taxonomically complex and morphologically diverse of all plant genera in the Crassulaceae family. Oftentimes sedum is referred to as a succulent. Succulents refer to any plants which have thickened, fleshy, and engorged parts that retain water in dry environments. The reason sedum is used for extensive green roofs over cacti is thanks to its extensive root structure and its natural tendency to only grow a few inches in height. This allows one sedum plant to entangle itself with numerous other root systems and overall improve the green roof's ability to overcome shear stresses.

Photo of Sedum Tiles in VAT

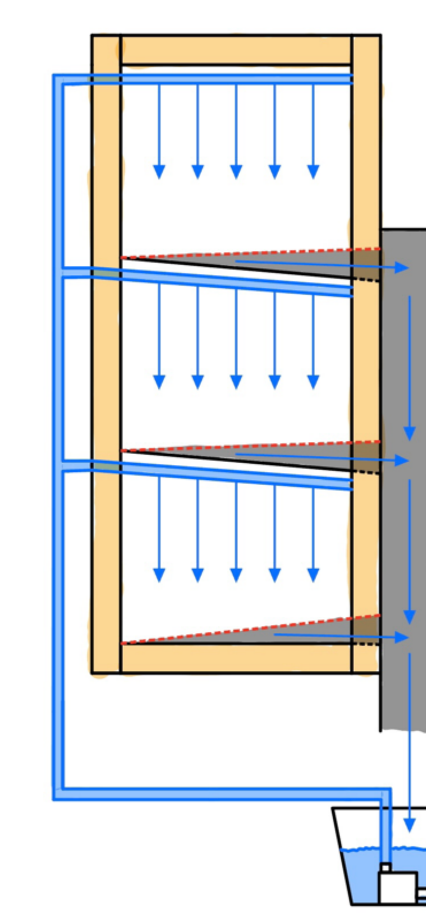
Irrigation Spike Design

- Manufactured with a 3D printer
- Features two levels of water dispersion
- Outer tube diameter is 7 mm, the size of the average cleat spike
- Inner tube diameter and lower two holes diameters are 3 mm
- Upper 8 holes have diameters of 2 mm
- Diameters and design may change as fluid mechanics of the setup is explored and spikes are tested with the pump and piping itself
- To be fitted to piping using t-joints



Rhino 7 CAD model

3D Printed Irrigation Spike



Water Distribution and Recollection Diagram for VAT