Cultivating research: resource-based design as an activating agent for energy and water conservation

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ABSTRACT: Green and living walls are an old idea made anew through the use of conventional construction materials used in new and creative ways. There is now a broad market for mass-produced prefabricated living wall systems that are made from PVC, metal, and or geotextiles. There exist hydroponic living walls made from geotextiles and fabric materials, rigid modular living walls made from PVC, and green façade structures made from cable and steel mesh to support ground-based vines. Most conventional materials for green walls in the market are derived from raw material or recycled PVC. This study investigates alternative materials already in the solid waste stream that were ready for creative reuse. The purpose of this project was to explore if existing sheet metal by-products could be repurposed as green wall systems and provide beneficial ecosystem services. A secondary purpose was to educate the campus community about sustainability through improving the value of industrial by-products thereby reducing waste streams in the production of new materials, energy conservation and reduced water use for green walls through the use of drought tolerant vegetation. Initial readings for the living wall system surface was 2.68 to 3.92 and up to 4.6 degrees Celsius cooler than the adjacent concrete wall. Students and faculty at Texas A&M university worked through a dozen different green wall modular designs. One design was refined and was trialed for cutting using a water-jet machine and assembled with manual folding. Three hundred prism shaped modules were attached to a vertical steel frame. Drip irrigation lines deliver water to each module. Drought tolerant plants were used to minimize irrigation water. It is estimated that compared to conventional living walls, the proposed system uses about half of the volume of water needed for irrigation. More detailed analysis is currently under investigation.

KEYWORDS: Resource reuse, Living Walls, Energy saving, Automobile metal By-products, Fabrication.

INTRODUCTION

Green walls began many decades go as simple installations with hanging plants on buildings and vines selected and planted to grow vertically on stone walls and then later brick walls. Wood trellises and pergolas became popular beginning in the mid-sixteenth century formal gardens (Baran and Gültekin 2018, Köehler 2006). The Chrystal Palace built for the 1851 World's fair in London was conceptualized by John Paxton and was perhaps the first inspiration for indoor and vertical greening with modern materials. The massive glass, steel and wood structure housed indoor trees, ferns, flowering and hanging plants. But these early versions of greening buildings only set the stage for the development of more contemporary hydroponic vertical gardens popularized by the French botanist Patrick Blanc since 2000 (Blanc 2008). Blanc's vertical gardens were each a custom fabrication and installation derived from fabrics, however many vendors began exploring materials and methods to mass produce similar living wall systems. Over the years there has been a limited number of investigations documenting the ecosystem services that green walls can provide, thus the technology is in an early adoption phase (Köehler 2006).

There is now a broad market for mass-produced prefabricated green wall systems that are made from PVC, steel meshes and or geotextiles (Perini et al. 2013, Manso and Castro-Gomes

2015). Green walls consist of a variety of techniques to establish live plants on vertical surfaces (Figure 1). Green facades are a type of green wall to establish twining vines on cable or on wire mesh panels. Hydroponic living wall systems make use of shallow rooted plants, fabric and nutrified irrigation water to feed plants. Each of these types of systems have limitations. Most vines have vertical growth limits and hydroponic systems may not be adaptable to climates with extreme heat or cold. Modular living wall systems attempt to grow plants vertically in small PVC containers. Many modular systems have fundamental problems such as; limited space to provide for growing medium and root growth, and some modular systems position plants in unnatural orientations such as perpendicular to sunlight. Initial installations of some of these modular living wall systems have demonstrated that some of these market-based modular systems have limited application outdoors in extreme climates and some may not be economically sustainable (Perini and Rosasco 2013, Dvorak et al. 2014).

Figure 1. Green wall systems include vines with adhesive root systems grown directly on walls (left image) modular PVC-based systems (middle) and hydroponic systems constructed from fabrics (right). Source: Authors

This study investigated alternative materials already in the industrial solid waste stream that were ready for immediate use (Ali 2017). The purpose of this project was to investigate if sheet metal by-products could be repurposed as a green wall system and provide beneficial ecosystem services. A secondary purpose was to educate the campus community about sustainability through adding value-by-design to the industrial by-products thereby reducing solid waste streams in the production of new materials, energy conservation and reduced water use for green walls through the use of drought tolerant vegetation.

1.0. METHODS

A mixed methodology including empirical, qualitative, and quantitative methods was used to investigates the potential for alternative use of fabrication materials and methods for living walls. The investigators engaged conversations with potential industry partners and secured agreements with an automotive manufacturer sheet metal by-product. The authors invited a group of interdisciplinary students to participate in a resource-based design-build process to develop and fabricate new modules for a custom living wall, secured resources for fabrication, installed the living wall system and pre-tested the wall for micro-climate characteristics.

1.1. Design and Fabrication

To investigate the potential use of alternative materials and methods, the investigators secured agreements with a waste stream source in the automotive industry for available sheet metal. The automotive industry fabrication process typically disposes large quantities of sizable galvanized sheet metal as a byproduct of the automobile manufacturing process. Students at Texas A&M university were invited to take a special topics courses to conceptualize modular living wall design alternatives and to assist in the fabrication process. Students and faculty prepared and presented materials to the university campus design sub-council to receive permissions to install the wall. After approvals, the modules and frame were fabricated, painted, planted and installed in place (Figure 2). Due to delays in the fabrication process, only the first third of the wall was assembled and planted in the month of May (Figure 2). Plant species included: *Dichondra argentea*, *Yucca* 'Color Guard', *Phyla incisa*, *Agave lophantha* 'Quadricolor', *Hesperaloe parviflora*, *Hechtia texensis* were placed in the modules and watered. The wall frame as shown in Figure 1 and comprises a support for the entire living wall. The living wall is approximately 5.48 meters wide and 4.26 meters high consisting of 23.41 m^2 of surface area. The remainder of the wall was fabricated and installed in place during the month of August.

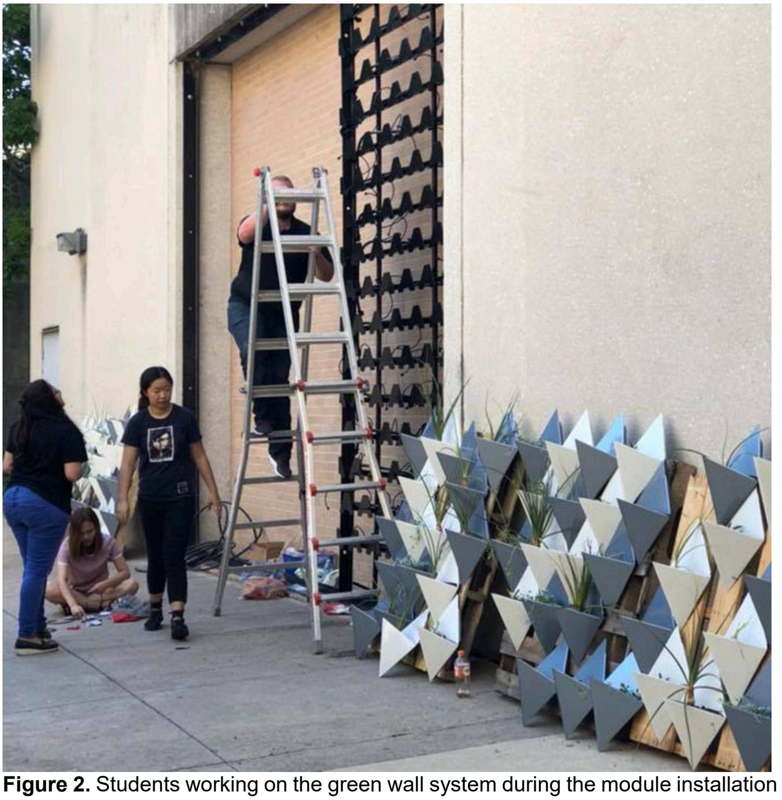

Figure 2. Students working on the green wall system during the module installation process. The concrete wall used to compare microclimate is visible to the right and left of the living wall. Source: Authors

1.2. Microclimate investigations

Students investigated several potential methods to measure surface temperatures and heat gain. The first method was through thermal camera imaging. A FlIR©® camera was used to capture a moment in time and reveal surface temperatures of the wall materials. A second method was used to determine the measure of the wall surface temperatures observed with a hand-held Extech IR©® infrared thermometer. The wall has a south/southwest aspect and data was collected during the late afternoon generally one to two hours after direct solar exposure. Surface temperatures were captured with an infrared hand-held device and recorded on a table. By measuring after direct solar exposure, the effect of the wall was recorded at the end of the solar exposure period. Twelve surface locations were identified to be measured daily near the same time for twenty-one days between the months of June and August on days without precipitation. Each located was measured three times and recorded. The average of the three measurements was used in this study. Surfaces measured included the planted light grey-blue colored modules and white modules, exposed brick, exposed concrete, two metal exterior doors and the immediate ground level pavement adjacent to the living wall. For each temperature reading, three temperature readings were taken and averaged. Additionally, A FIIR thermal camera was used to crosscheck thermal variance on wall surfaces.

1.3. Watering

Drip tube irrigation lines were installed to deliver municipal water to each module. A zone control valve was set to deliver water once daily at 6:00 am. Each drip tube is capable of delivering approximately 3.7 liters per hour. Irrigation was set to run daily for two minutes duration or 0.126 liters per day.

2.0. RESULTS

The living wall system designed and fabricated by students and faculty was successfully developed and installed during late 2018. The first phase included planted modules and was installed in May. The remaining modules and frame (without plants) were installed during the month of August. Twelve students meet once weekly to fabricate the modules in a fabrication lab at the university. Later, students installed the irrigation system, retention fabric in the modules, light-weight soils and plants.

By the month of August, all of the modules had been fabricated and the entire frame was installed. All of the modules had been hung on the wall. However, the remainder of plants will be installed during the spring of 2019, as faculty and students, and additional materials were needed to grow and purchase. Some faculty and students were not available until spring 2019.

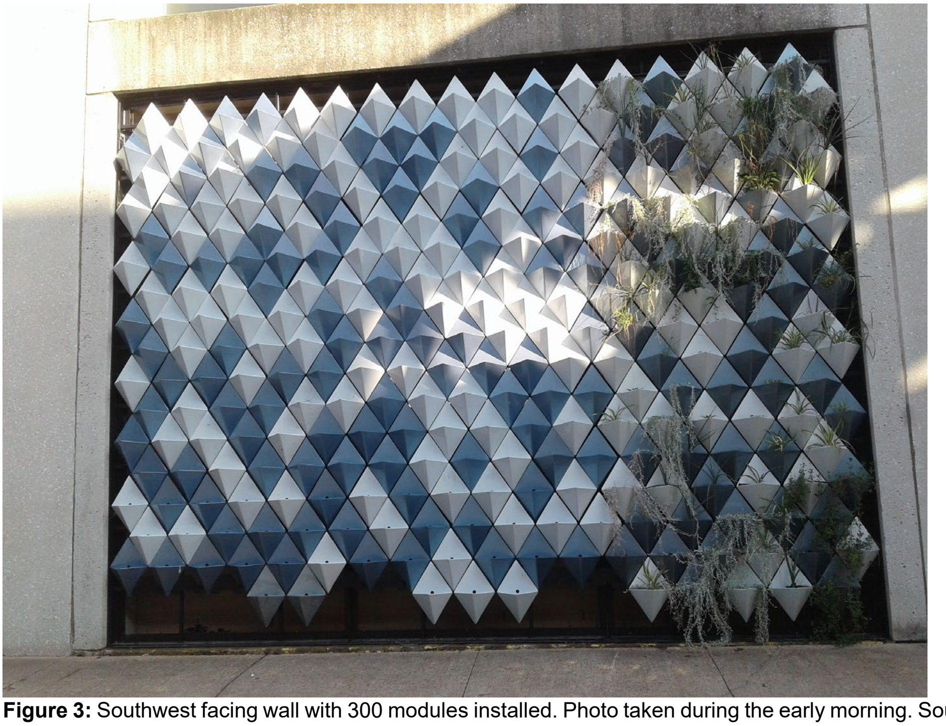

Figure 3: Southwest facing wall with 300 modules installed. Photo taken during the early morning. Source: Authors

2.1. Waste stream reduction

Compared to market-based modular living wall systems, this system designed by students and faculty used materials already in the metal solid waste stream. By retrieving refuse sheet metal from the automotive industry, there was no need to extract raw materials. Figure 4 shows the sheet metal used prior to fabrication of the wall. Each sheet was fitted for the module design and cut. Waste from the cutout of the module could be sent back into a metal recycling center. The module layout was adjusted to minimize cuts and reduce waste.

Figure 4. Sheet metal scraps in bundles prior to fabrication at the university (left) and after fabricating (right). Source: Authors

2.2. Microclimate

Surface temperature observations were taken over the summer from June to August. The thermal camera image demonstrates that the living wall modules (blue pixels) on average were 2.68 to 3.92 and up to 4.6 degrees Celsius cooler than the adjacent concrete walls (orange to red pixels). There was some variation between modules as the white modules were generally 1-2 degrees Celsius cooler than the light grey modules. Figure 5 shows the temperature variation in a thermal camera image of the wall taken in July. The image legend is located on the right side of the image and correlates pixel color to thermal temperature with a range of 28.3 to 32.9 degrees Celsius.

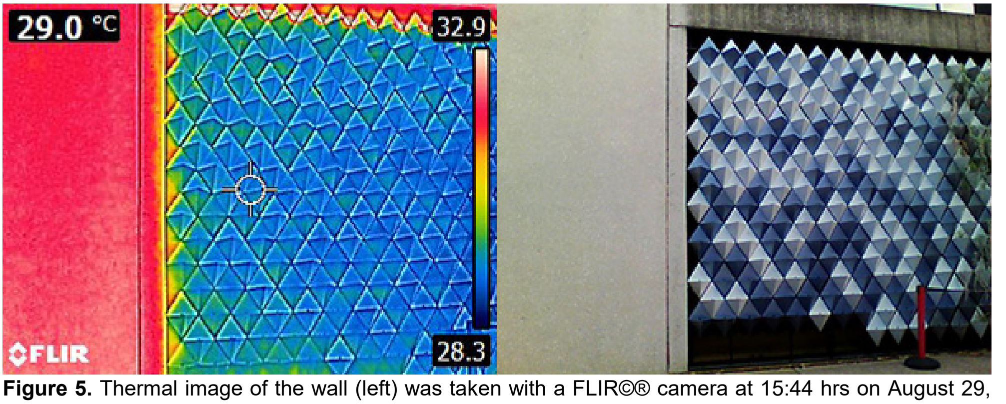

Figure 5. Thermal image of the wall (left) was taken with a FLIR©® camera at 15:44 hrs on August 29, 2018. The heat energy visible in the image is latent heat, as the wall has a southwest exposure and was in shade approximately two hours prior to the photo. The white circle on the left center of the thermal image locates the 29.0 °C. The planted modules include darker blue pixels on the right side of the image. Source: Authors

Although cloud cover was present during some of the observations, during the warmest time of the summer temperature readings were taken during cloudless days to measure potential effect of modules. Table 1 shows mean temperatures for several locations of different surfaces. As the modules are diamond shaped and protrude away from the wall, the sun and shade sides of modules were taken. The building wall also has two metal exterior doors and some exposed light brown brick. The grey-blue module in the shade side of the module had the lowest surface temperature at 39.78 °C for the living wall. The white modules had temperatures similar to the grey-blue modules but were slightly warmer. Most of the living wall is in the blue temperature range, where the edge near the concrete wall can be seen in the green and yellow temperature range. This means that the concrete thermal mass is radiating heat to the living wall system (Figure 5).

Table 1. The handheld Extech infrared thermometer was used to observe floor surface mean temperatures taken at 15:00 hrs on August 1, 2018 approximately two hours after direct sunlight. Maximum air temperature for the daytime at the university was 36 °C.

Surface number	Surface material	Surface Temperature °C
1	Grey-blue Module	41.12
2	Grey-blue Module (shade)	39.78
3	Grey-blue Module (sun)	40.66
4	White Module	40.8
5	White Module (shade)	40.72
6	White Module (sun)	41.22
7	Exposed Brick Wall	42.78
8	Right Concrete wall	41.42
9	Left Concrete wall	42.48
10	Metal door	42.59
11	Right Concrete pavement	44.77
12	Left Concrete pavement	49.77
13	Exposed Brick pavement	48.27

2.3. Watering

Irrigation water was delivered daily during the summer. During late July, the watering was changed from two minutes to one-minute duration. Some weeds were establishing in the modules and it was thought that it may be due to excessive watering. On October 18, 2018 it was discovered that the irrigation control valve was leaking. The irrigation was shut down for the winter, as natural rainfall was assumed to be ample for the remainder of the year. Compared to earlier studies on living walls on campus, this living wall system was set to half the water, due to the use of drought tolerant plants. The same type of water delivery system was used on three other living walls built from conventional systems available on the market. Irrigation run times of five to ten minutes was required to irrigate the entire wall thoroughly. In this study we found that the living wall planted with drought tolerant vegetation did not require more than one to two minutes of irrigation daily to maintain live growth.

3.0. DISCUSSION

Compared to other conventional living wall systems available on the market, the uniquely-designed galvanized sheet metal modules minimized the use of new materials, steel recycling, and therefore energy consumed. The custom modules required paint, similar to typical car finish to extend their life time and to protect the galvanized metal from oxidation and corrosion. The thermal data demonstrates that the living wall compared to a concrete wall has a capacity to reduce the heat gain on exterior wall surfaces. The effect of plants is not clear, as only one-third of the wall was planted. The cooling effect was largely due to the effect of unplanted modules. The additional systems layers of plants, soil, insulation, and moisture are anticipated to further reduce the heat gain on exterior surfaces. The thermal images show that the plants were the coolest features of the wall. Once the wall is complete, further investigation will be conducted. The warmest measured locations were the ground pavement near the wall. It is presumed that the pavement near the wall received direct solar exposure from sunlight and radiated heat energy from the wall surfaces. Future studies will investigate the potential effect of plants shading and cooling on the wall and pavement adjacent to the wall.

CONCLUSION

This study demonstrated that sheet metal by-products can be harvested and repurposed to reduce solid waste streams and embodied energy through resource-based design approach, typically present in the manufacturing of living wall modules constructed of PVC materials. A more in-depth investigation is necessary to further investigate energy conservation of all phases of fabrication and to better understand the dynamics of the potential heat energy conservation of this living wall system. The use of drought tolerant vegetation allowed minimal watering to gain effect of shading the modules. Future studies will investigate the fully planted wall to extrapolate the results.

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