UBC Social, Ecological Economic Development Studies (SEEDS) Student Reports

UBC Student Union Building Living Wall Design Proposal

Stephanie Wilson

Brittany Hilbrecht

Wen Li

Jordan Cowan

Wilson Tran

Jacky Ling

University of British Columbia

MECH 457

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1 Background & Intent of Project

'As a leading university, UBC has a mandate to "promote the values of a civil and sustainable society"[1]. The satisfaction of this mandate requires that sustainability be a key component in campus projects and expansion. One such project is the construction of a new Student Union Building (SUB). With the decision to construct a new SUB, the Alma Matter Society (AMS) SUB committee completed extensive research into the expectations and desires of stakeholders (such as faculty, staff, and students). An important factor was found to be the development of a greener campus (see Student Survey Results in Appendix A). To fulfill UBC's mandate of sustainability and to meet the expectations of community members, the SUB committee has requested the design of this 'Living Wall' for the new SUB building. This project will provide a visible reminder to both the internal and surrounding communities of UBC of the importance of sustainability. This project will contribute to UBC's ability to promote the campus, increase sustainability ratings, and improve annual reports on UBC's initiatives and sustainability. It will also further initiatives to obtain a LEED Platinum+ rating for the new SUB building, as well as contribute to the objectives of the UBC SEEDS program.'[2]

In addition to sustainability, modularity was identified as a key requirement. The Living Wall will be located in the atrium of the new SUB. As the atrium is fully designed at this time, it is imperative that the wall be flexible in both shape and size, so it may be incorporated into the atrium. To fulfill the requirements of a fully functioning, modular, and sustainable living wall, four system requirements were further identified: an internal cellular structure, a support structure, an irrigation system, and vegetation. A fifth requirement, Marketing and Education, was added to ensure the public and users of the SUB are both aware of the wall, and understand its functionality and contribution to sustainability. The internal cellular structure is required to house the vegetation, while allowing for modularity and flexibility in shape and size. The support structure is required to provide a framework for the cellular structure and irrigation system. The irrigation system is required to provide water for the corresponding vegetation system, which is a requirement by nature of a Living Wall.

Sources of information and assistance can be found in Appendix N – 'Acknowledgements' and Appendix P – 'References'. To gain the most from this experience, each team member has completed an individual reflection on the project, available in Appendix O – 'Project Reflections'.

[1] Retrieved from http://www.ubc.ca/about/accountability on September 10, 2009.
[2] Replicated from the Project Proposal, available in Appendix I - Project Proposal Report.

2 Summary of Existing Solutions

The concept of a vertical garden as a Living Wall is not a new idea; several Living Walls are in existence around the world. In addition, many pre-fabricated Living Wall panels are available for purchase. In the design of a Living Wall, existing products and technologies must be carefully researched to avoid infringing upon current patents, as well as to avoid wasting energy and time reinventing current technologies. Research was successful in providing information on Living Wall systems as a whole and their individual sub-functions. A reference report was created to contain all of the research gathered and can be seen in Appendix J – 'Reference Report'. Living walls can be categorized into two types, those with climber plants that grow across a wall and those with plants that grow from the wall outwards.

The simple wall climbers generally contain vines or ivy, and rarely include blooming flowers or edible vegetation. They are easy to install and maintain, and provide good thermal insulation. Wall climbers can often be seen in nature, but due to their limited plant variety and possible damage to existing structures, they are not a top choice for indoor or outdoor living walls.

The most common living wall is one that can support a wide variety of vegetation and provides good air filtration. A living wall system is typically created from several identical cells attached to a separate supporting structure. These cells can come in many different shapes and sizes and can be filled with a variety of vegetation to create a unique design. The concept of the living wall as a system is a relatively new idea, and thus little is known about its lifetime. What has been tested is the impact the wall has on its environment and how it can purify and filter out several contaminants and provide a safer and more enjoyable atmosphere. One of the most intriguing living wall systems researched was created by Patrick Blanc. He creates highly expensive living wall masterpieces without the use of soil, instead he has his plants attach to a vertical felt which is held up by a steel structure. Unfortunately, the plants that are capable of attaching themselves to a felt are very limited.

Ideas were taken from living walls visited (including Vancouver Airport and Whole Foods), and researched (including Patrick Blanc, Queen University, and ELT Living Walls). The felt used by Patrick Blanc was the inspiration to use a capillary mat behind the cells for irrigation, and as visible in these existing living walls, a system able to sustain numerous varieties of vegetation was deemed a requirement early in the design process.

3 Overview of Project

The living wall proposal is uncovered in five sub-sections: internal cellular structure, support structure, irrigation, vegetation, and marketing and education. A description of the wall can be drawn from the first three topics. The wall consists of a modular cell structure, to allow the size and shape of the wall to be variable. This cell is sectioned into smaller divisions, each of which houses a single plant (Figure 1).

Figure 1 - Cell prototype

These cells are backed by a capillary mat and mounted onto a support structure. The capillary mat serves to take up water from the irrigation system and allow the vegetation and soil to absorb water from the mat (Figure 2).

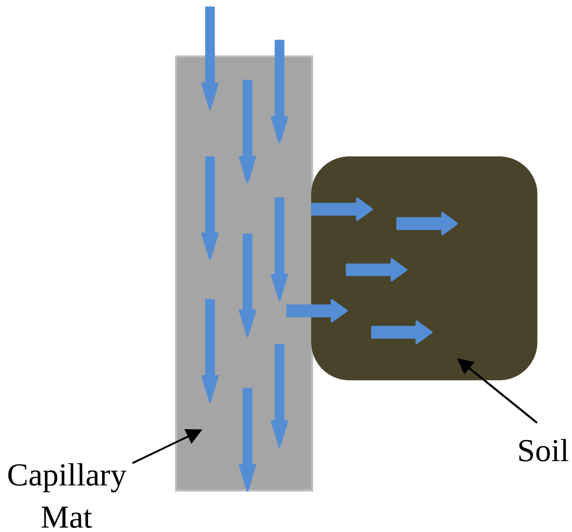


Figure 2 - Absorption of Water

The soil will only absorb water until it is sufficiently saturated, similar to a sponge. The irrigation system provides a continual source of water to the capillary mat, using sensors to ensure enough water is provided without overfilling the system. Finally, excess water that is not absorbed by the plants is recycled back into the system.

This design process was guided by course requirements and several documents have been produced to date in keeping with these requirements. These reports are available in Appendix I - Appendix M. The result of this guided process is a functioning prototype (Figure 3) and this report.

Figure 3 - Prototype

The structure of the individual cells is discussed in detail, and specific recommendations are made. The irrigation system is also discussed in detail, including discussion of prototype and testing results. Critical requirements and general recommendations are discussed and suggested for marketing and education, support structure, and vegetation. A cost estimate for construction and annual operation is made, based on the systems and components suggested in this report. The report concludes with a summary of conclusions drawn, based on the work done by this design team, as well as recommendations for the continuation or finalization and implementation of this project.

4 Assembly

The assembly of the wall requires several main components: support structure, plastic sheet, capillary mat, cells, upper and lower troughs, and irrigation system. The irrigation system consists of sensors, valves, piping, a pump, and a filter. Detailed technical drawings are available in Appendix B – 'Detailed Parts & Assembly Drawings'.

The horizontal and vertical beams forming the main support structure are bolted together using corner brackets. The structure is then secured to the atrium structure with wall anchors and long bolts, extending into the wall.

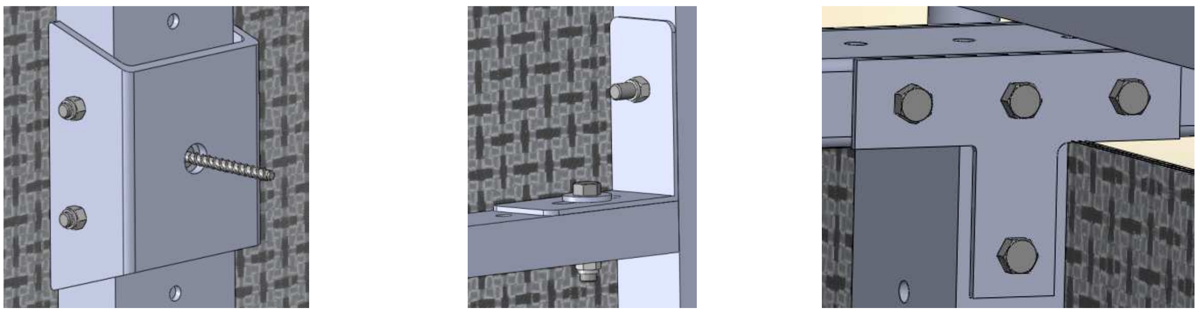


Figure 4 – Brackets & Wall Anchor

The upper trough will be secured to the support beams at the top of the structure; the lower trough secured at the base. A rigid vapour barrier is secured to the structure, followed by sheets of the capillary mat. The rigid barrier reaches from the base of the wall to the edge of the upper trough.

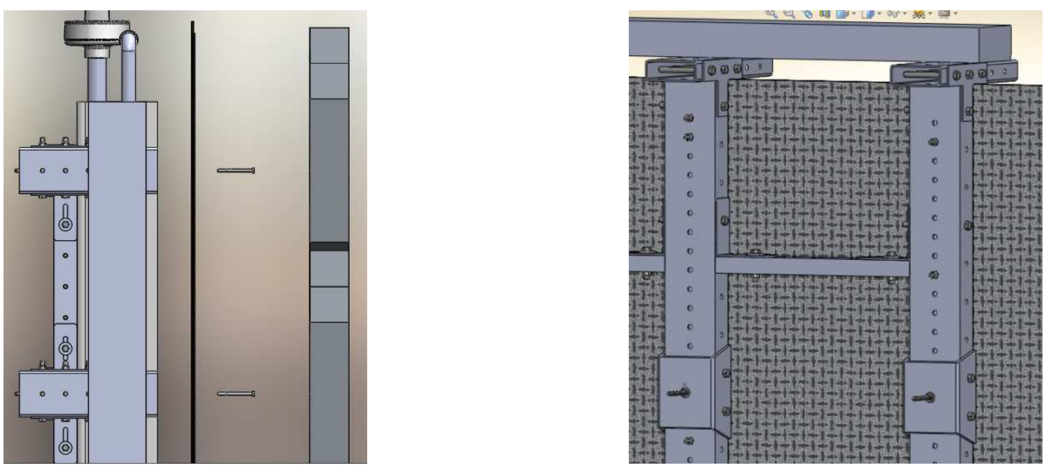


Figure 5 - Upper trough & Layered Side View

The capillary mat extends from inside the upper trough to the lower trough. These layers are held in place with small rivets. Cells must be premanufactured and assembled as described in Section 5; plants must be pre-grown as directed in Appendix H. The cells are then secured through the two layers and into the main support structure at two points; one at the top point of the cell and another at the bottom point of the cell.

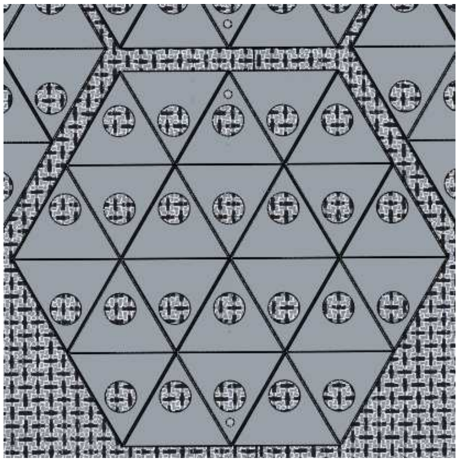


Figure 6 - Cell attachment

The recycling pump will be located either in the lower trough or beside the trough with a direct connection. In case of system failure and subsequent overflow, the top trough includes a drain to the lower tank, as does the bottom trough include a drain to the waste water system of the building. Piping from the pump runs to the filter system and then to fill the upper trough (for simplicity, drains and filter not shown). Additional piping feeds into the upper trough to allow for additional water to enter the system, as controlled by the sensor logic. This system is to include valves as necessary; the integration of sensors is discussed in Section 7.5.

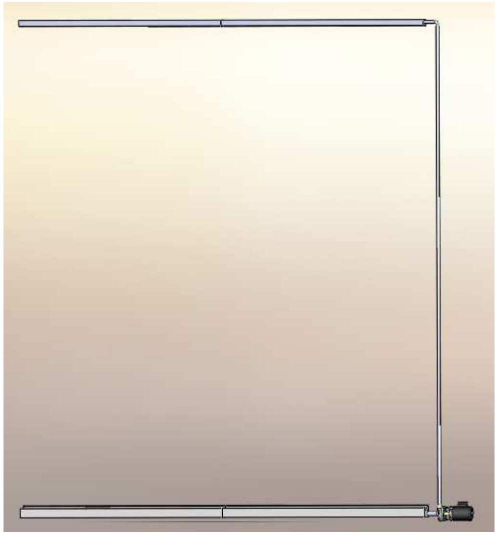


Figure 7 - Irrigation System

5 Cell Structure

5.1 Requirements & Evaluation Criteria

The cell structure is to be composed of modular hexagonal cell units. Each modular hexagonal cell unit consists of 24 triangular sub-divisions. The choice of the hexagonal form was the result from an empirical analysis of its feasibility, and benefits, in terms modularity, structural support, and communications and educational merits. The hexagonal form is proven to be modular in its shape and very strong in its structure. Communicational and educational merits are namely in the hexagonal form's association to carbon structure, honeycomb, biology, life, interconnectivity, and community building (see Conceptual Alternatives Report in Appendix K). Each equilateral triangle subdivisions has a side length of 6.25 inch. The hexagonal cell structure is then extrapolated to a side length of 12.50 inch (see Drawing B13 in Appendix B).

5.2 Manufacture

The manufacturing of wall cells will consist of the following processes,

1. Water Jet Cutting — In this process the water jet cutter will cut out the shape of all components and their respective openings from sheets of stainless steel sheet metal with precision.

2. Sheet Metal Folding — The folding process will make folds along the lines as shown in the diagram to build up the two edges and the three inner walls of the hexagonal cell. Additional bends of component is required for the side guards.

3. Assembly — The assembly of the cell wall components will require two steps, first rivet the two side guards to the main folded cell body, then slot in 3 parallel dividers and then another 3 parallel dividers to complete the cell subdivisions.

Further details and drawings can be found in Appendix C.

5.3 Recommendations

Material — Due to the low production volume of the living wall cells, it is more economical and sustainable to go with a metal construction rather than a plastic construction.

Dimensions — The size of the subdivisions is constrained to a depth of 3.40inch, and an area of about 10 cm square. The dimension requirements are made in response to the optimal soil compaction configuration to allow healthy plant and root growth, as recommended by Douglas Justice of the UBC Faculty of Land & Food Systems.

Safety — The handling of thin stainless steel sheet metal can be dangerous as the edges can be very sharp. Use of protective gloves during the handling, construction, installation and maintenance of the cells and its components is recommended.

Sheet Metal Folding — This process can be completed manually with fluency in approximately 10-15minutes per cell. This process could be further automated in an industrial manufacturing setting. A metal fabrication manufacturer should be consulted for large volume order of custom parts.

6 Support Structure

6.1 Requirements & Evaluation Criteria

The support structure for the Living Wall does not need to be complex. Functionally, it must have the strength and rigidity support the Living Wall and it's systems. The shape and form of the support structure is constrained to allow individual cells to be mounted onto it. It should be corrosion resistant, and as sustainable as possible. The support structure should require minimal space while allowing room for maintenance. Finally, the structure must be constructed with a safety factor, as failure of the structure could result in serious injury or death.

6.2 Recommendations for Implementation

It is recommended that the structure be determined by persons with extensive construction and structure knowledge, as this should be a relatively small task for a person with experience. Based on the design team's limited research and knowledge, a structure comprised of vertical and horizontal beams is recommended. The vertical beams allow individual cells to be mounted directly to the structure; the horizontal beams provide further support and rigidity. This structure may be secured to the wall with wall anchors, to provide sufficient support without requiring extra space. The sustainable material should be readily available at low cost; steel is suggested.

7 Irrigation System

7.1 Requirements & Evaluation Criteria

The irrigation system must ensure that there is a continuous source for the capillary mat to draw water from, as well as providing a sufficient amount of water to make up for the amount lost through plant absorption, evaporation, and potential minor leakages. It also needs to be designed to ensure that these conditions are continually met through potential power outages and electronic failures. To maintain sustainability, the system will recycle unused water, and should minimize energy requirements.

7.2 Irrigation Processes & System

The watering system begins by pumping water into the top tank from a source. This source can be a city sourced line or could be a collection of rain water. The capillary mat is submerged in the top tank, and water is pulled through the mat in a siphon-like manner. The water flows into the lower tank where it is re-circulated using a pump. The pump is activated by the float switch in the top tank.

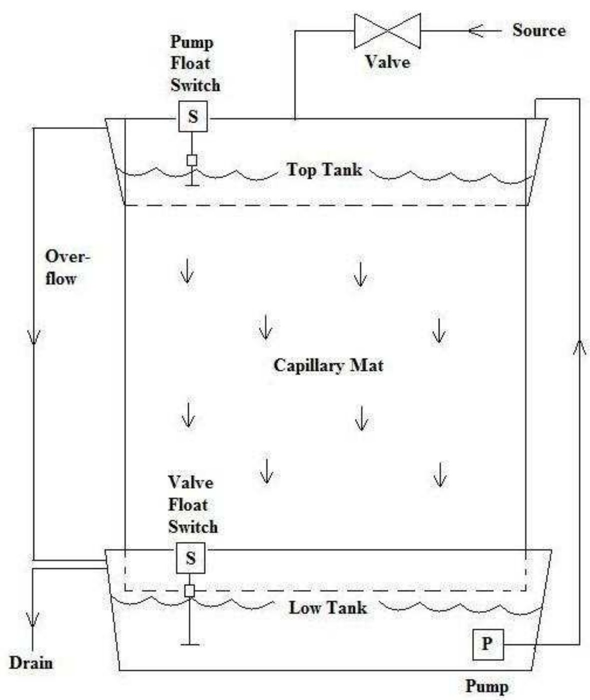


Figure 8 - Irrigation System Water Flow

Re-circulating the Water

As discussed in the Appendix M - 'Technical Analysis Report', if the capillary mat is left to dry out, it will no longer siphon water and needs to be replaced. A safety window of one hour was determined through testing at 20ºC and 50% RH before the mat is completely dry. This is a significant issue as changing the mat involves taking down all the cells of plants, and putting up new mat. As a result, the safe route is not to allow the mat to dry out; this is accomplished by re-cycling water immediately when the top tank is low.

Float Switches

The pump float switch controls the pump based on an upper and lower limit of water in the top tank. When the low limit is reached, the pump turns on. When the upper limit is reached, the pump turns off. The lower limit is not critical. However it is important not to set the upper limit greater than two inches from the top rim of the top tank. When the siphon mechanism begins, the capillary mat cannot pull water up more than two inches. Therefore when choosing the overflow pipe diameter, it must be smaller than 2 inches.

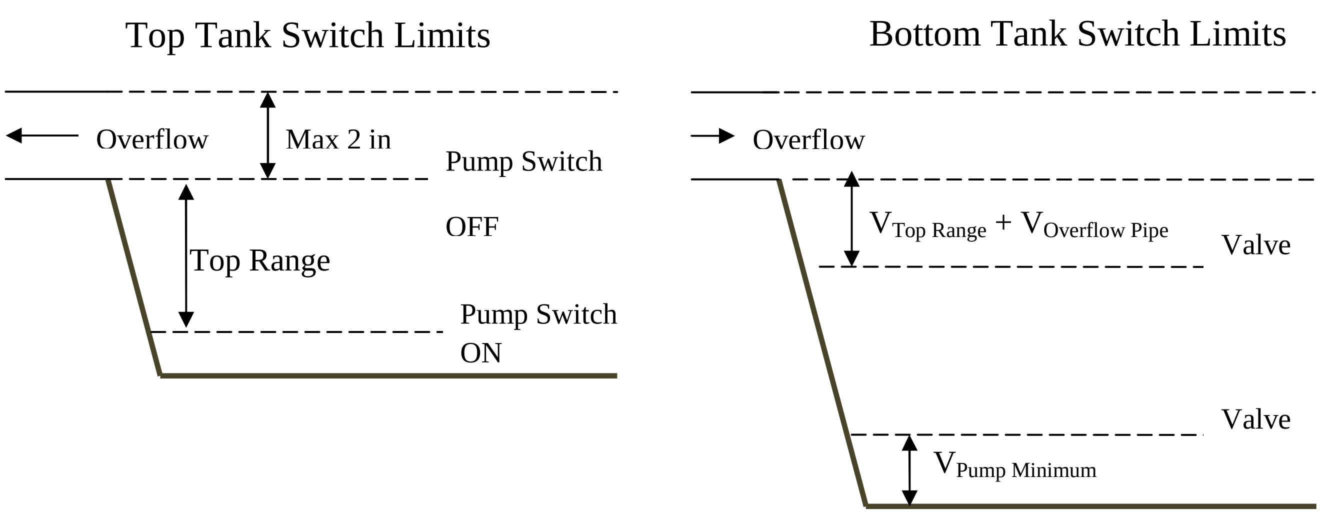


Figure 9 - Irrigation Switch Limits

The valve float switch in the bottom tank opens and closes the valve based on its own upper and lower limits. The lower limit is based on the minimum volume of water the pump requires ($V_{Pump\ Minimum}$). The upper limit is based on the volume of water in the top range ($V_{Top\ Range}$) plus the volume of water in the overflow pipe ($V_{Overflow\ Pipe}$). This ensures the water is always high enough for the pump to operate and low enough such that no water is wasted into the drain.

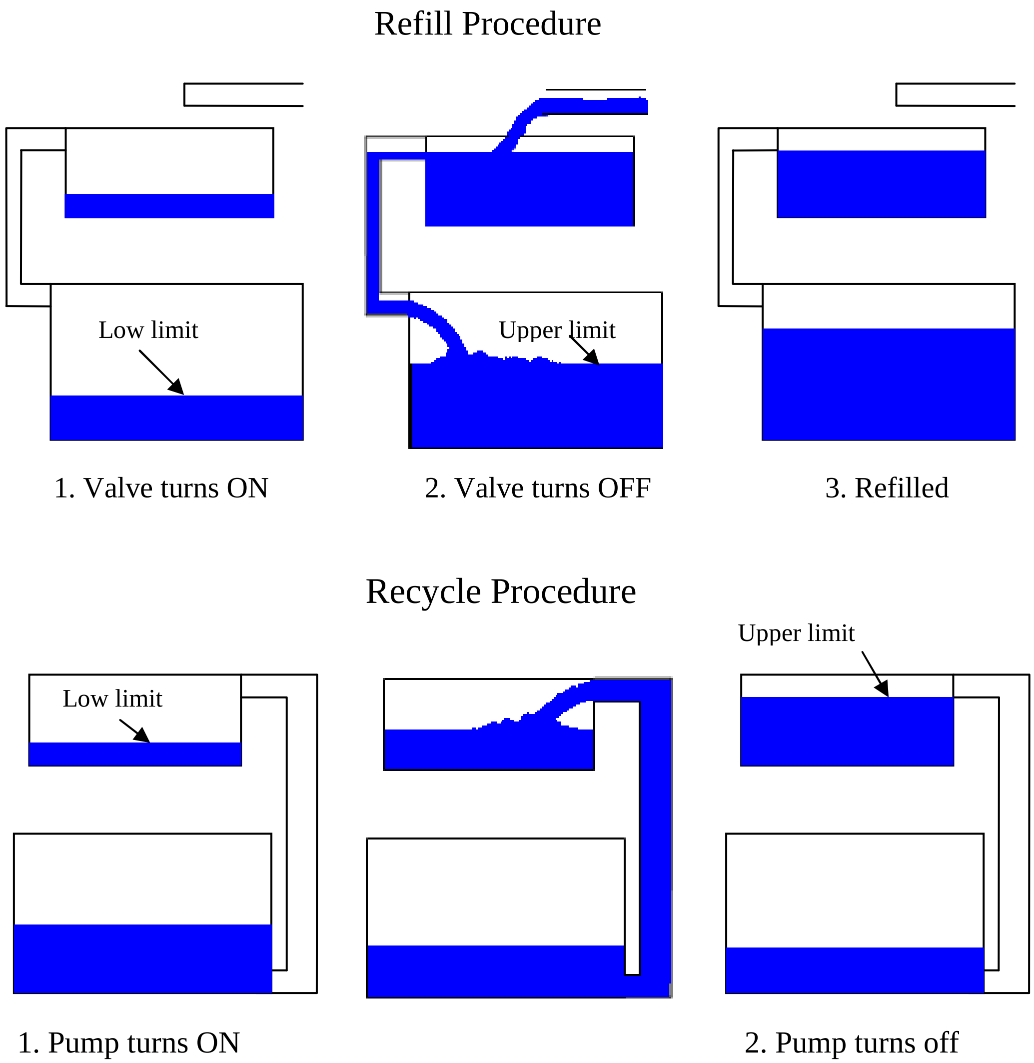


Figure 10 - Refill & Recycling Depiction

Sizing the Tanks

Sizes of the tanks will have to be ranked against indoor regulations on standing water. The only critical factor is that the lower tank is larger than the top tank. This will ensure that the top tank always sees the same amount of water being re-circulated regardless of how much water is lost to the plants and through evaporation.

Overflow

It is possible for the pump, or the source, or both to get stuck on. Therefore the overflow should be sized to handle the combined flowrate of both the source and the pump. This is a fail safe design which allows the system to continue working even during a malfunction. The lower tank will also need an overflow which can be directed to a drain. The lower overflow should only be used when flushing the system or if there is a malfunction.

When the bottom tank level is low, the valve switch opens the valve and water is brought in from a source. The source water will typically be coming in at approximately city water pressure, 10 gpm. The top tank is filled until it reaches the top overflow which sends the water to the lower tank. Since the overflow pipe is gravity fed, the maximum flow rate is limited by frictional and boundary layer effects only. Tables with maximum diameter and flow rate values are readily available from many sources online for further calculations.

When examining a control volume of the top tank, we see that the wick rate of the mat and the evaporation rate are very small relative to the pumping rate and the source rate. Therefore they are not considered in calculations for this section. Evapo-transpiration from the felt is discussed in the following section.

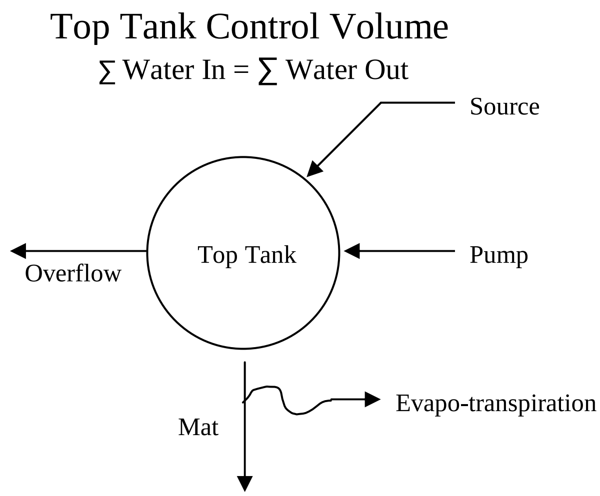


Figure 11 - Irrigation Control Volume

Wall	Pump Rate (gpm)	Source Rate (gpm)	Overflow Needed (gpm)	Pipe Dia (in)	Max Allow (gpm)
60’ x 15’	10	10	20	1.5	35
45’ x 30’	26	10	36	2.0	55

Table 1 - Irrigation Flow Requirements

Wiring

The wiring of the system is very simple. The pump float switch is connected to the pump. As well, the valve float switch is connected to the valve. The two systems are independent from each other.

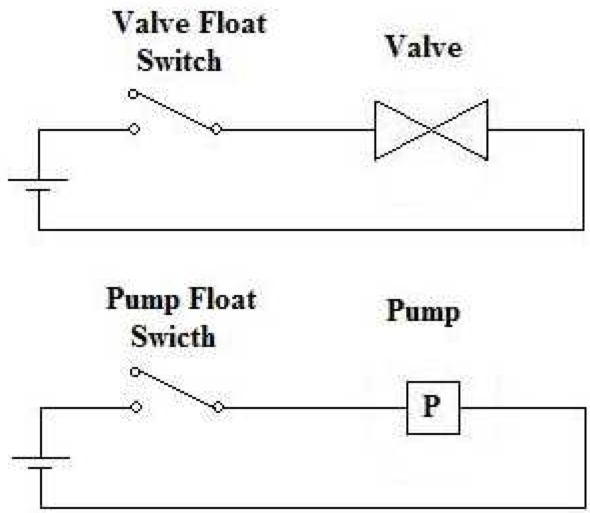


Figure 12 - Irrigation Switch Wiring Diagrams

State	Input	Output
Off	0	0
Recycle	Pump Switch = ON Valve Switch = OFF	Pump = ON
Refill	Valve Switch = ON Pump Switch = OFF	Valve = OPEN
Recycle and Refill	Pump Switch = ON Valve Switch = ON	Pump = ON Valve = OPEN

Table 2 - Irrigation State Diagram

Back-Up Precautions:

In an FMEA (available in Appendix D – 'FMEA'), some potentially costly situations were determined which require back-up systems. If the float switch in the top tank doesn't turn the pump on, the capillary mat will dry out and it will need to be replaced. A back-up float switch and pump could be installed to avoid this problem. They should be connected to a separate outlet in case there is an electrical short or if there are any power issues.

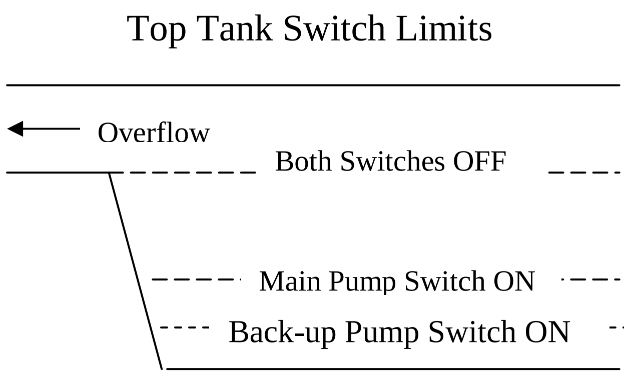


Figure 14 - Overflow Precautions

Also, if the valve float switch fails to open the valve, the system will eventually dry up. Therefore, a low water level alarm should be installed in the bottom tank below the low limit of the switch.

In the case when there is a power outage, the system should route to running a constant source of water to ensure the capillary mat doesn't dry out. This could be a back -up line which is input directly into the top tank.

7.3 Evapotranspiration

Evapotranspiration accounts for the water lost due to transpiration and evaporation. From our Technical Analysis Report, we determined estimates for plant drying rates through experiment. The plants were fully saturated at about 45% wet basis water content and lost an average of 0.28% water content per hour or 6.72% per day. A single plant in the wall holds approximately 600 g of dry soil. Therefore it will absorb 490.9 g of water to become fully saturated. After one day, one plant is expected to lose 119 g of water.

The prototype was monitored over a week to confirm evapotranspiration predictions. The prototype of 24 plants expected to see a daily water loss of 2.85 L. Data from the test is displayed in the graph below. The plants were kept indoors where the temperature stayed between 16-20 ºC and the relative humidity stayed between 37% and 48%. Note the vertical points are where the system was refilled. A maximum of 2.95 L/day and an average of 1.6 L/day were lost by the 24 plants. The early estimate of 2.85 L proved to be high but was still close the measured values.

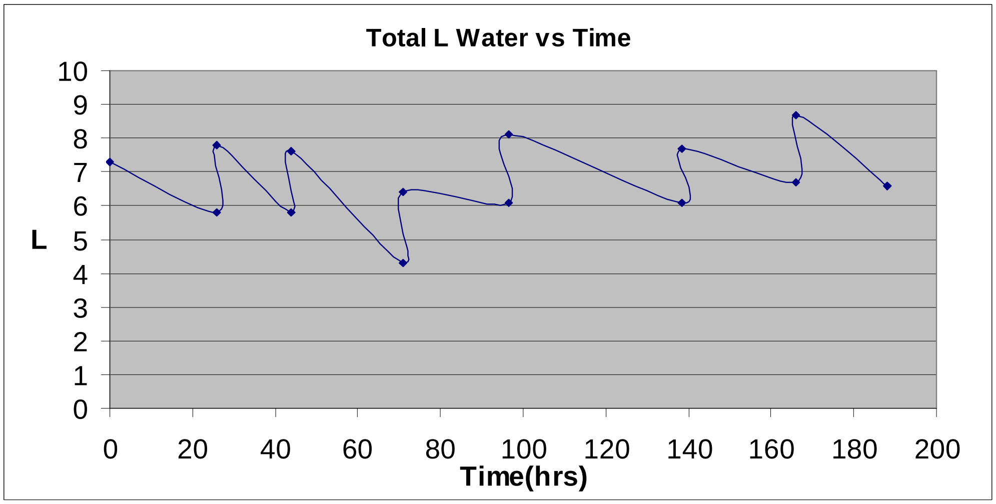


Figure 15 - Measured Evapotranspiration

Using the measured average of 66 ml of water lost per plant per day, this can be extrapolated to a larger wall. The system must be refilled with the amount of water which is lost to evapotranspiration. Therefore, this could be thought of the water consumption of the system.

Width (ft)	Height (ft)	Cells	Plants	Est Transpiration (L/day)
15	60	250	6000	395
30	45	375	9000	592

Table 3 - Estimated Evapotranspiration

As this consumption is very high, it is recommended that further design changes be made to reduce the losses due to evapotranspiration.

7.4 Energy Requirements

For a wall with dimensions of 60 feet of height by 15 feet of width, the energy requirement to recycle the water amounts to 0.497 kW-h per day, or $18.14 per year in costs at $0.10 per kW-h. For a wall with dimensions of 45 feet of height by 30 feet of width, the energy requirement to recycle the water amounts to 0.382 kW-h per day, or $13.94 per year in costs at $0.10 per kW-h. Calculations can be found in Appendix D. For both cases, the pump suggested is a 1 ½ HP pump with 1 ¼” discharge size, and a maximum of 69 feet of head rise at shutoff.

7.5 Recommendations for Implementation

When implementing the irrigation system with the wall, it is recommended that estimates are made to take into account the humidity of the environment and its effects on the evaporation rate of the system. As well, an analysis should be done to determine the effect of the positioning of the wall would have on water losses through direct sunlight or shading.

8 Vegetation Recommendations

8.1 Requirements & Evaluation Criteria

The plants will be contained in a public environment. Therefore, the following things should be considered in plant selection.

Criteria	Questions
Hypoallergenic potential	Are people allergic to this plant or anything associated to this plant?
Sunlight requirements	Can this plant survive with little direct sunlight?
Water requirements	How much water does this plant need to survive?
Counteracting chemicals	Does this plant have air filtration potential?
Appropriate growth rate	Will this plant take overtake other plants in the cell? Does this plant require intensive maintenance?
Appearance	Does the plant look good and fit the design of the wall?
Functional Vale	Does this plant provide anything edible? Does it make the room smell nice?
Fertilizer requirements	Does this plant need constant fertilization to survive?
Seasonal adaptabilities	Can this plant survive the winter conditions?
Environmental impact	Is this plant native to Vancouver? Is it easily grown indoors from a seed?

Table 4 - Vegetation Requirements

8.2 Recommendations for Implementation

It is recommended that each plant cell should contain a handful of activated charcoal to inhibit bacteria growth and a time release capsule for long term nutrition. For growth in the prototype, pansies were recommended by an industry expert. Herbs were also established in the prototype, to demonstrate how the wall could be used to contribute in other ways. Selection of plants is a complex issue as there are many factors to consider. Extensive knowledge of plant systems and the interaction of plants with their environment is critical. It is recommended that the selection of plants for this application be left to vegetation experts.

9 Marketing & Education Recommendations

9.1 Requirements & Evaluation Criteria

The design of the living wall is required to communicate and exhibit UBC's commitment to sustainability and community engagement. The proposed hexagonal cell structure has been well received with positive response as outlined in the Conceptual Alternatives Report in Appendix K.

9.2 Recommendations for Implementation

It is recommended that the implementing the education and marketing components of the living wall would be pursued by members from the schools of education, business, and communication design. Drawing resources from the schools mentioned would further advance the living wall's ability to communicate its educational merits as a commitment to sustainability and as educational tool.

To further communicate the functionality of the living wall system, one may consider adding additional sensors for reading real-time data on the soil, water, and plant conditions from the living wall. Readings from the sensors can be exhibited via LCD displays, LED displays, or from the University Website. Communication of the living wall system and functions can also be exhibited through static information panels (see Conceptual Alternatives Report in Appendix K).

10 Estimated Construction & Operation Costs

As the design of the new SUB atrium is not complete, a final cost estimate cannot be known. To show the variation of cost with wall size, two areas are considered: 60’ high by 15’ wide, and 45’ high by 30’ wide. Cost of construction and operation is given as an approximate proportional dollar amount, as well as for each area of wall. Detailed costs and price quote sources can be found in Appendix G – ‘Detailed Estimation of Construction Costs’.

10.1 Construction Cost Estimate

Construction costs include material costs only. Where possible, bulk ordering rates have been taken into account.

Sub-Group	60’ x 15’ Total	45’ x 30’ Total
Structural	$61271.44	$92603.80
Irrigation	$1352.62	$1250.02
Vegetation	$4741.20	$15016.80
Grand Total	$67365.26	$108870.62

Table 5 - Estimated Construction Costs

10.2 Operation Cost Estimate

Operation costs are given as an average annual cost. These costs are based on the maintenance plan outlined in Appendix H – ‘Suggested Operation & Maintenance Procedures’.

	60’ x 15’ Total	45’ x 30’ Total
Average Annual Cost	$2395.82	$8123.62

Table 6 - Estimated Operation Costs

11 Recommended Operation & Maintenance Plan

Following the construction and installation of the structure and irrigation systems of the Living Wall, specific start-up procedures are suggested to ensure the success of the wall. These include items such as testing the timing of the irrigation system and the initial growth of vegetation. Suggested start-up procedures are available in Appendix H – 'Suggested Operation & Maintenance '.

Ongoing operation of the Living Wall system will require a combination of Condition-Based Maintenance (CBM) and regularly scheduled Preventative Maintenance (PM). Components such as pumps and water troughs will be subject to CBM and should be regularly inspected and replaced only if necessary. CBM is applied to elements that are costly to replace or where failures are obvious and non-critical. Components such as the felt, plants, and soil of the wall will be replaced at two year intervals. These components depend on PM as failure may not be obvious or may have significant consequences. A suggested schedule of maintenance and detailed maintenance procedures are found in Appendix H – 'Suggested Operation & Maintenance '. Cost requirements for both PM and CBM are as discussed in Section 10 – 'Estimated Construction & Operation Costs '.

12 Recommendations for Further Research & Implementation

While much was accomplished over the course of this project, the Living Wall is not yet fully designed or ready to be implemented in the SUB atrium. Further progress is required, especially in the areas of vegetation, marketing, and education.

To ensure the success of the wall and the life and growth of the vegetation in it, expertise is required to determine what plant life is best suited to this application and environment. Proper marketing and education methods will allow the UBC community and surrounding communities to understand the importance of sustainability, and the contribution the wall makes to a sustainable building and environment. Further testing and research can also be contributed to the irrigation system, to ensure efficiency and sustainability. The rate of evapotranspiration should be decreased if possible, and the effect the wall will have on the humidity of the atrium should be determined.

The results of this project are due in part to the contribution of many people. These persons may be able to further contribute to the completion and implementation of the project; contact information can be found in Appendix N.

Appendix A Student Population Survey Results

General Survey Summary

June 29, 2009

Author: Jensen Metchie, AMS

Table of Contents

1.0 Introduction

The SUB Renew Team has conducted student consolations to assess the specific needs the new Student Union Building (SUB) must fulfill. To date there have been 10 themed workshops held at UBC in October and November, 2008, that resulted in the student directed program of the building. The Final program was published in Feburary 2009 and a 10 day open-house occurred in March/April 2009. The General Survey held online in April 2009 is a continuation of this process with the specific intent of refining certain aspects the building program and services.

The primary concern to be addressed by this survey is the relevance the new SUB's services, businesses and space organization has on achieving the ultimate goal of creating a more engaging student community on campus. Each question aims to uncover: A) how much a specific service or space will be used, B) to was degree do student see such a service or space improving the campus community, C) alternate ideas to improving the service or space usage and viability.

The data collected in this survey has been reviewed by the AMS (Alma Mater Society) SUB Renewal coordinators with the SUB Renewal Team and the findings and suggestions have been added to SUB Schematic Design Program.

2.0 Participation Summary

The General Survey was aimed at all UBC students. A separate survey for graduate students was available online at the same time. Below is a brief summary of the survey's participants:

Started the survey	1,549	
Completed the survey	1,433	
Education Level		
Undergraduates	1,029	
Graduates	257	
Post-Graduates	26	
Not a student	7	
	Survey	UBC[1]
Full-time students	1,237	31,375
Part-Time students	86	19,917
Proximity to UBC Campus		
On UBC Campus	28.0%	
In Vancouver	54.7%	
Outside Vancouver	17.3%	
Time spent on Campus (during school year)		
Monday-Friday	75.5%	
Weekends		
Usually-Sometimes	58.3%	
Rarely-Never	41.7%	
Club involvement (At least one)	497 (32%)	
Have Children (any age)	60 (3.9%)	
Faculty	Survey	UBC[2]
Arts	33.8%	31.6%
Science	26.3%	18.6%
Forestry	2.7%	
Applied Science	9.3%	8.8%
Business/Commerce	4.7%	8.8%
Education	4.0%	11.8%
Medicine	2.6%	

[1] Figures from *UBC Facts & Figures (2008/2009)* for UBC Vancouver: (http://www.publicaffairs.ubc.ca/ubcfacts/index.html).
[2] Figures based on Degrees Awarded for 2007 from *UBC Facts & Figures (2008/2009)* for UBC Vancouver: (http://www.publicaffairs.ubc.ca/ubcfacts/index.html).

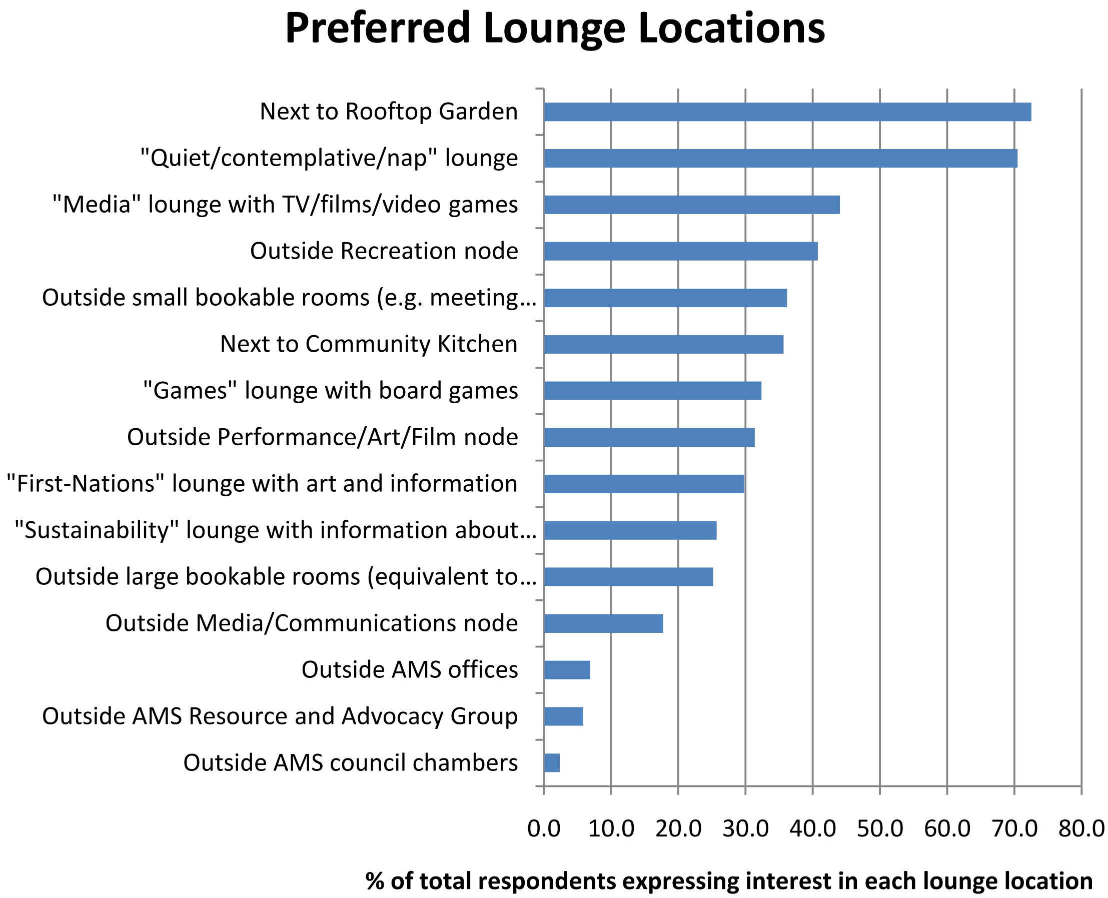
The breakdown of the students that responded was close to an accurate representation of the student faculty demographic with the majority of respondents in the faculty arts, followed by science, and then applied science.

3.0 Building Spaces

This section covers several aspects of the new SUB's general space. The intention of this section is to identify what types of spaces students need the most and what feature students would like to have in the space.

3.1 Lounges

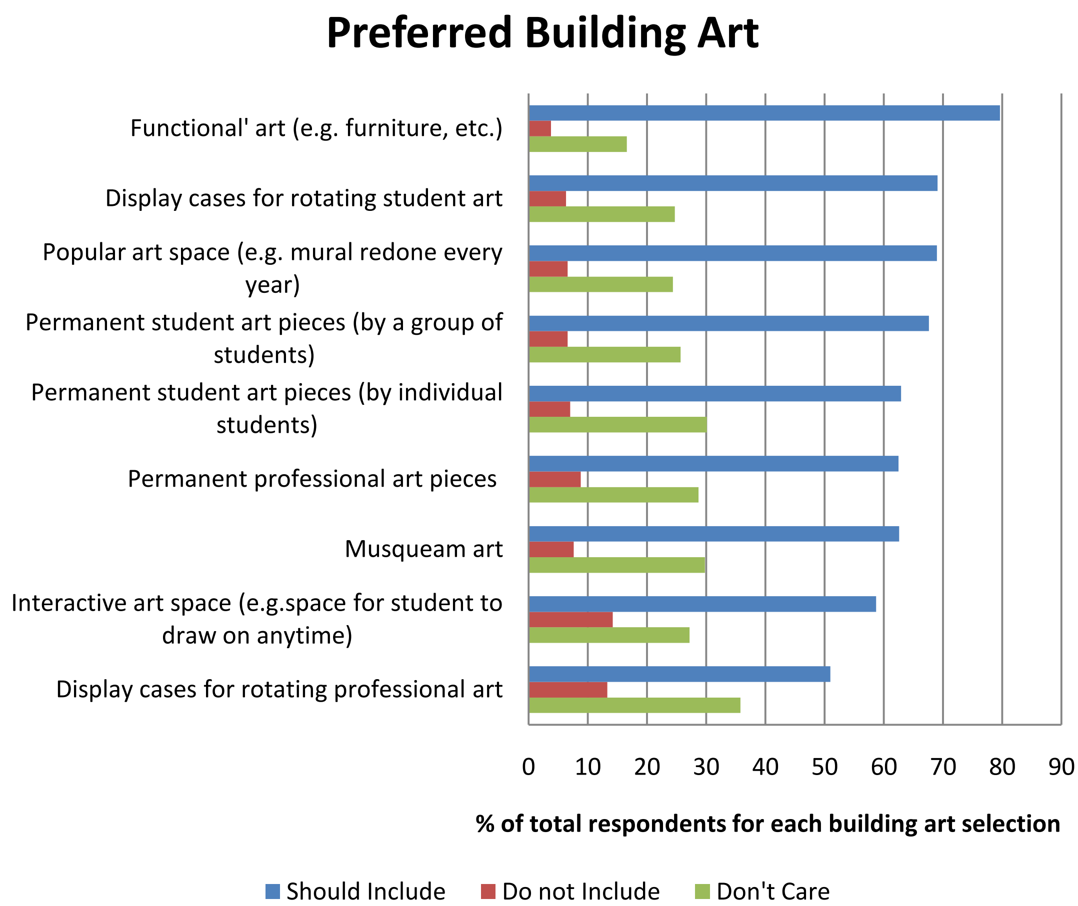
Lounges will foster a sense of community among students and will be distributed among other components in the new SUB to establish activity nodes. To encourage activity and participation, lounges need to be properly designed and positioned to attract students and encourage interaction. The SUB must also try to reach out to all students at UBC by providing spaces that will meet as many students' needs as possible as allowed within the project's budget. The following is list of potential student lounge types in descending order according to expressed preference.



The two most popular types are a rooftop garden lounge and a quiet/contemplative/nap lounge. Section 5.4 (Preferred Eating Locations) shows a strong preference to eating outside in a climate controlled patio indicating that the rooftop garden lounge should also be equipped with tables and chairs for students to eat on. In the comments for this question, many people have requested a place to study. The quiet contemplative lounge may be equipped with furniture to meet this purpose (e.g. desks, cubbies), or be kept as strictly a space for relaxation equipped with couches with an additional space for studying.

3.2 Art

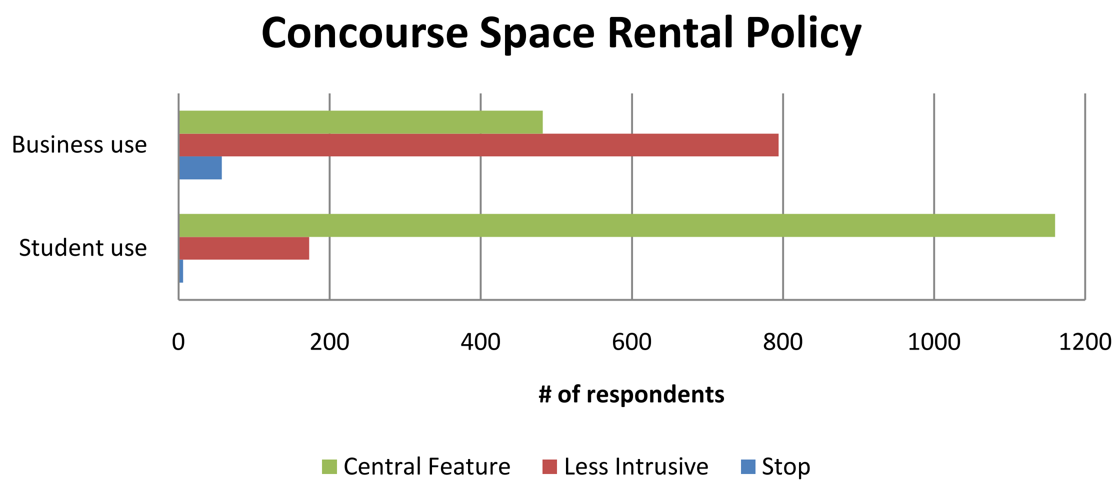
The art that fills the interior and exterior of the building can affect the manner in which students interact with the space. Art that is student produced can also add to building a sense community by providing a forum for student expression and appreciation. The following list shows support for potential art programs for the new SUB.



The highest level of support is for functional art with 459 respondents stating this as an important feature to be added to the new SUB. Following functional art are display cases for rotating student art and popular art space. Generally, the survey indicates high support for student art and art that will reflect changes over time.

3.3 Concourse

Currently the SUB rents out its concourse space to businesses and student organizations. Student organizations are most present during club days. Businesses are present throughout the year except when the concourse is used for other purposes. The survey asked respondents to indicate their preference for each type of use and in which policy direction the AMS should pursue for the new SUB. The following graph shows the responses.



An overwhelming number of respondents want student use to be a central feature of the main concourse with business use to be less intrusive.

3.4 Bookable Spaces

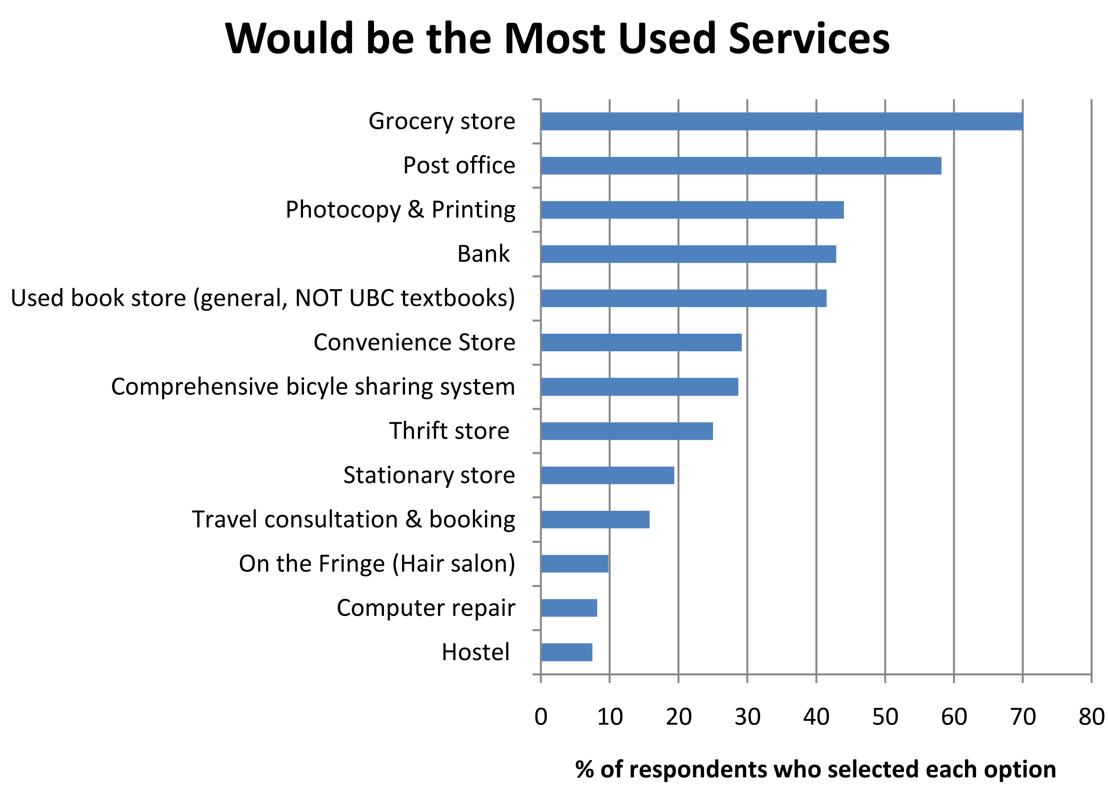
Roughly 1/3 of respondents indicated that they would use a sound proof room equipped with a piano at least once a term. However, only 12% of respondents indicated that they would use it at least once a week. This level of interest indicates that while this space will be used at times, use may be infrequent and sporadic. The question is whether this space will contribute to the SUB's overall goal of improving the sense of student community on campus. As a result of this survey, multi-functional rooms have been added to the program with one room including a piano.

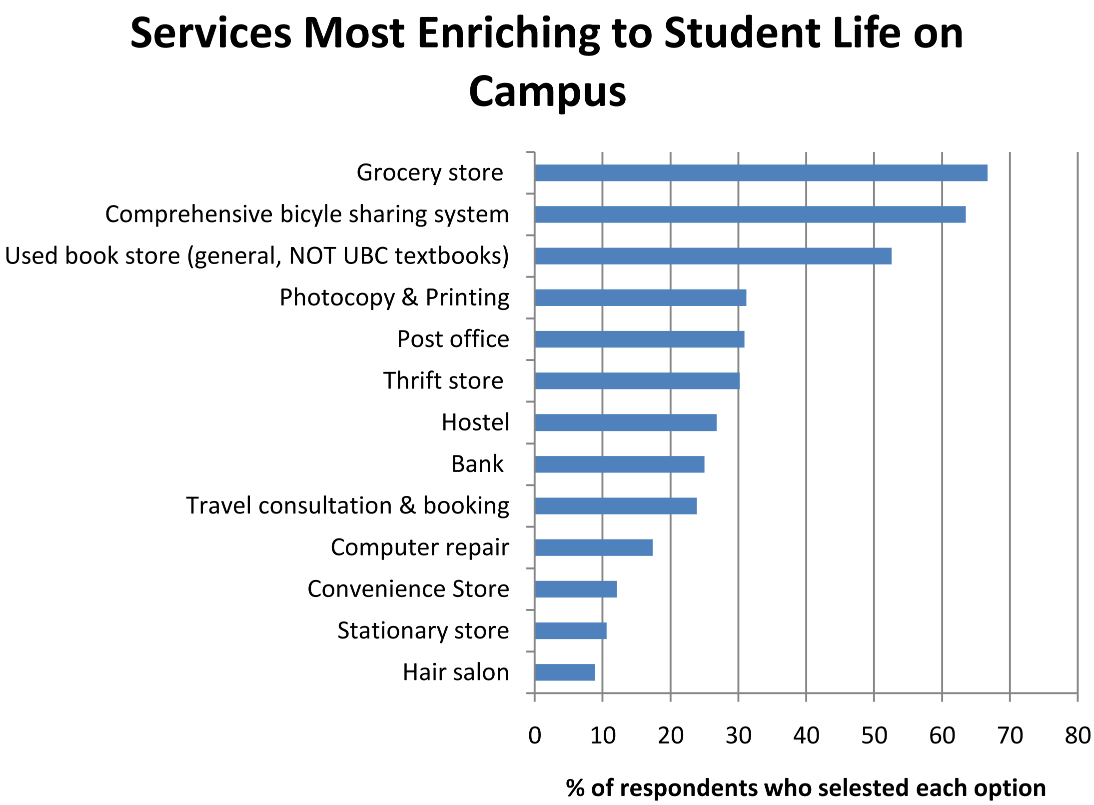
4.0 SUB Services and Businesses (excluding Food services)

This section covers the services that will be provided in the new SUB and student support for each service. The intention is to identify how much each service would be used and how best to implement each service. For some services it is necessary to identify where the respondents live in relation to UBC so as to understand what type of student would be most likely to use the service.

4.1 Student Life on Campus

The primary aim of the AMS and the new SUB is to encourage a more inclusive and enriching campus experience for students. The services that are provided in the new SUB need to be well used and must contribute to improving the student community. The following two graphs identify which services respondents believe would be most used and which service would most contribute to enriching student life on campus.

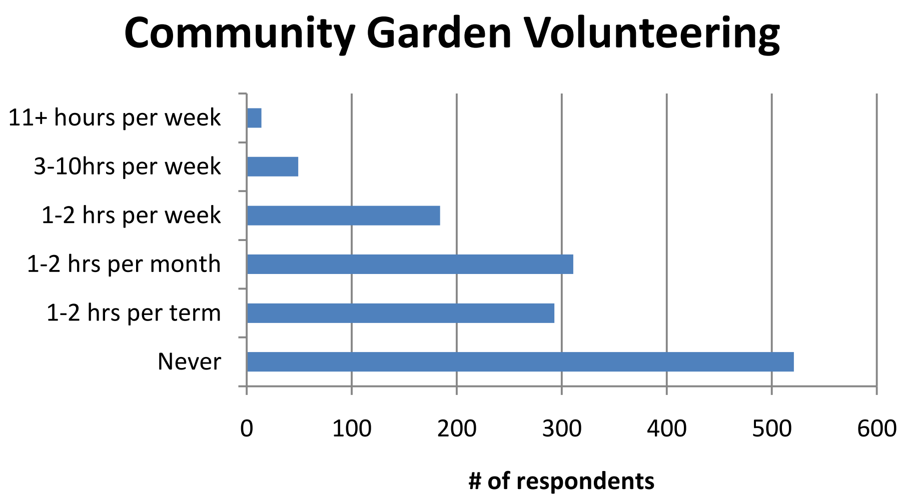




The general consensus among respondents is that the most used services would be the grocery store followed by a post office, photocopying and printing, a bank, and a used bookstore. Similarly, the services most enriching to student life are a grocery store, a comprehensive bike sharing system, and used bookstore. These results indicate a desire for the new SUB to be similar to a town centre; a place where students can go to perform daily errands and leisure activities that will encourage interaction with the UBC community. Interestingly, grocery store is listed as both the most used service and the most enriching to student life on campus. Considering that the UBC campus currently does not have a grocery store, though one is planned for the South Campus development, this result is not surprising.

4.2 Community Garden

A community garden may be located on the roof or somewhere else around the new SUB. Respondents were asked how much time they would be interested in volunteering to work in the garden. The following graph displays the responses.



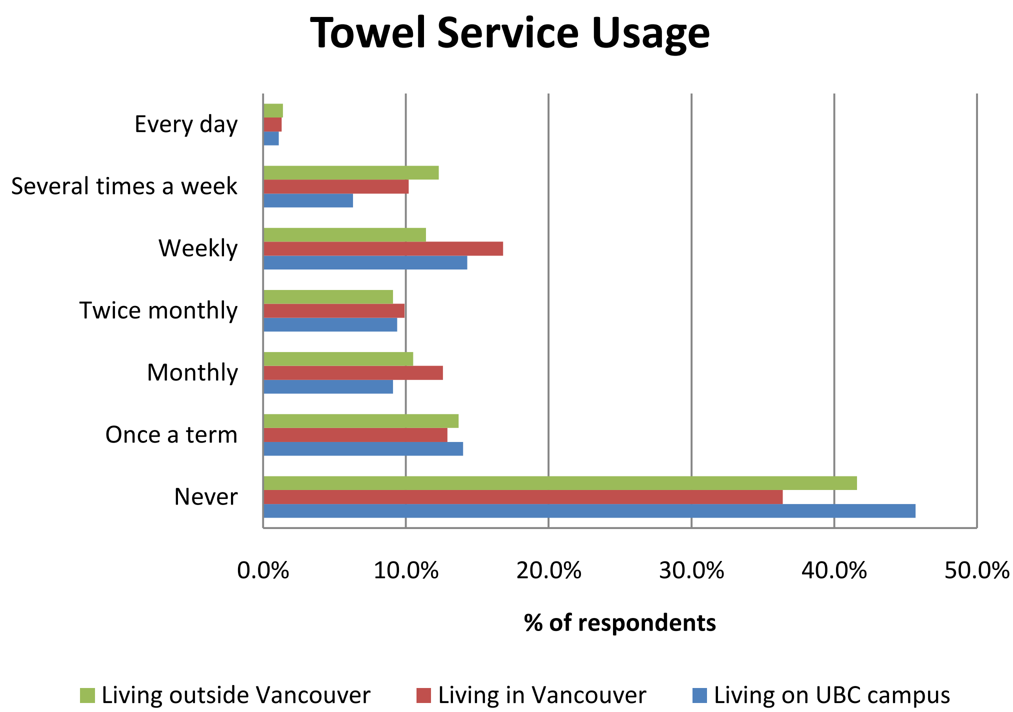
A large proportion of respondents, roughly 2/3, indicated some interest in working the community garden. Of those interested, most would be willing to work a few hours on a once a term to once a month basis. This level of interest would be sufficient to maintain such a garden.

4.3 Lockers and Towel Service

There will be showers and lockers in the new SUB. Management of this service has yet to be determined. The survey has several questions pertaining to student interest in lockers according to various management schemes and services to enhance the usage and viability of the showers.

4.3.1 Towel service

A towel rental service is proposed to promote usage of the showers. The following lists the interests in a towel rental service separated by respondents' living location.



Towel service shows highest interest with those living in and outside Vancouver, with roughly 60% stating they would use it at least once a term and over 25% would use it at least once a week. Most respondents commented that they would use this service when commuting to UBC by bicycle. In the 2007 UBC Transportation Survey, 5.1% of trips to UBC were reported to be made by bike, based on the survey responses, and only 1.2% was actually observed to be made by bike. The SUB Renewal Team has concluded to add a service counter next to the locker facilities that can be converted into a reception area if need for a towel service is confirmed.

The following table summarizes the maximum charge respondents would be will to pay for a towel service.

Pay by use system

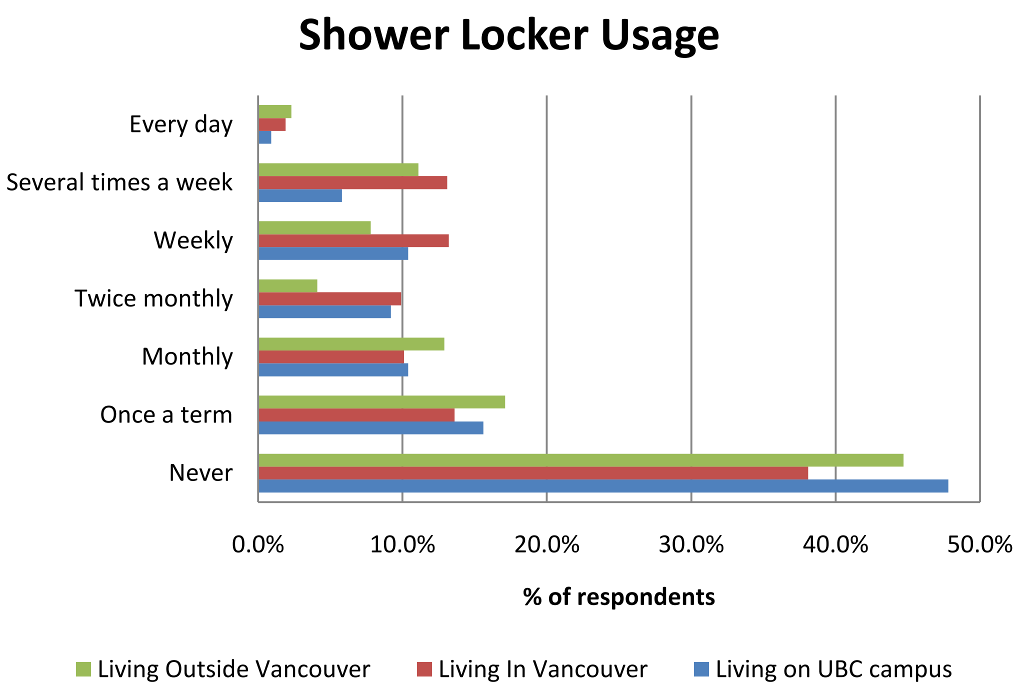
maximum charge	I'd never use it	I'd only use it if it were free	25 cents	50 cents	$1	$2	$4
% willing to pay	27.7%	21.1%	14.5%	15.4%	16.0%	5.1%	0.3%

Pay by term system

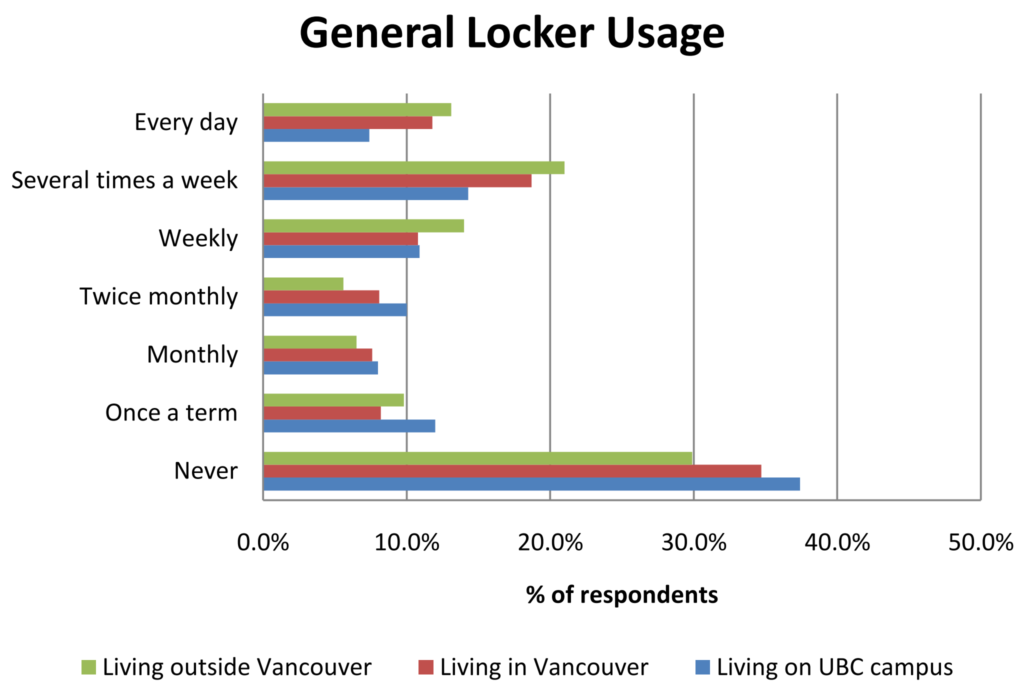
maximum charge	I'd never use it	I'd only use it if it were free	$5	$10	$20	$40	$60	$100
% willing to pay	35.1%	24.0%	17.3%	14.0%	6.7%	2.1%	0.5%	0.20%

4.3.2 Lockers

Lockers can be in two forms: shower lockers located in a changing room and general lockers located in a hallway or locker room. The following graphs show the response for each type of locker separated by respondents' living location.



Those living in Vancouver show more interest in shower lockers than those living outside Vancouver or on UBC campus. Based on the comments, this interest can be related to bike commuters wanting a place to shower before classes. The responses indicate that shower lockers would be used more irregularly, once or several times a week but rarely every day.



Interest in general lockers is higher for all three groups, with those living outside of Vancouver showing the most interest. Many responded to using it several times a week to every day indicating more regular usage. This high interest in every day usage will certainly impact the locker management system, prompting some if not all general lockers to be rented on a by-term/by-month basis.

The following table summarizes the maximum charge that those who would use the service would be willing to pay:

Pay-by-day system

Maximum charge	Free	25 cents	50 cents	$1	$2	$4
% willing to pay	31.6%	36.3%	17.9%	11.1%	2.7%	0.3%

Pay-by-term system

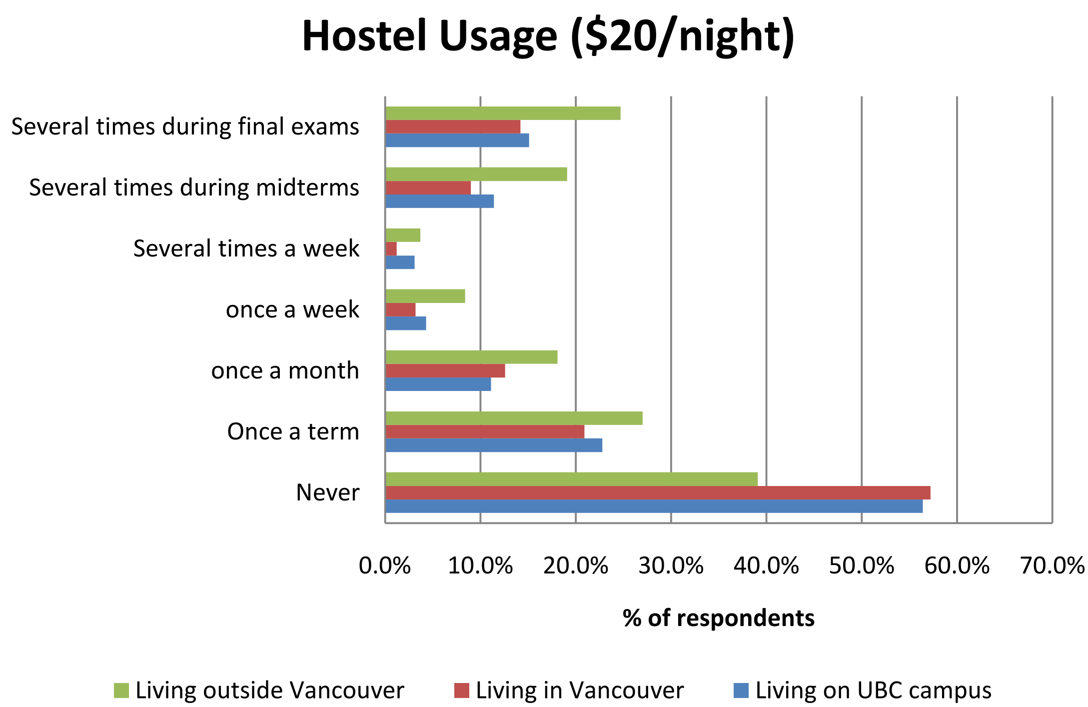
Maximum charge	Free	$5	$10	$20	$40	$60	$100
% willing to pay	29.1%	22.8%	22.8%	16.7%	6.6%	1.4%	0.5%

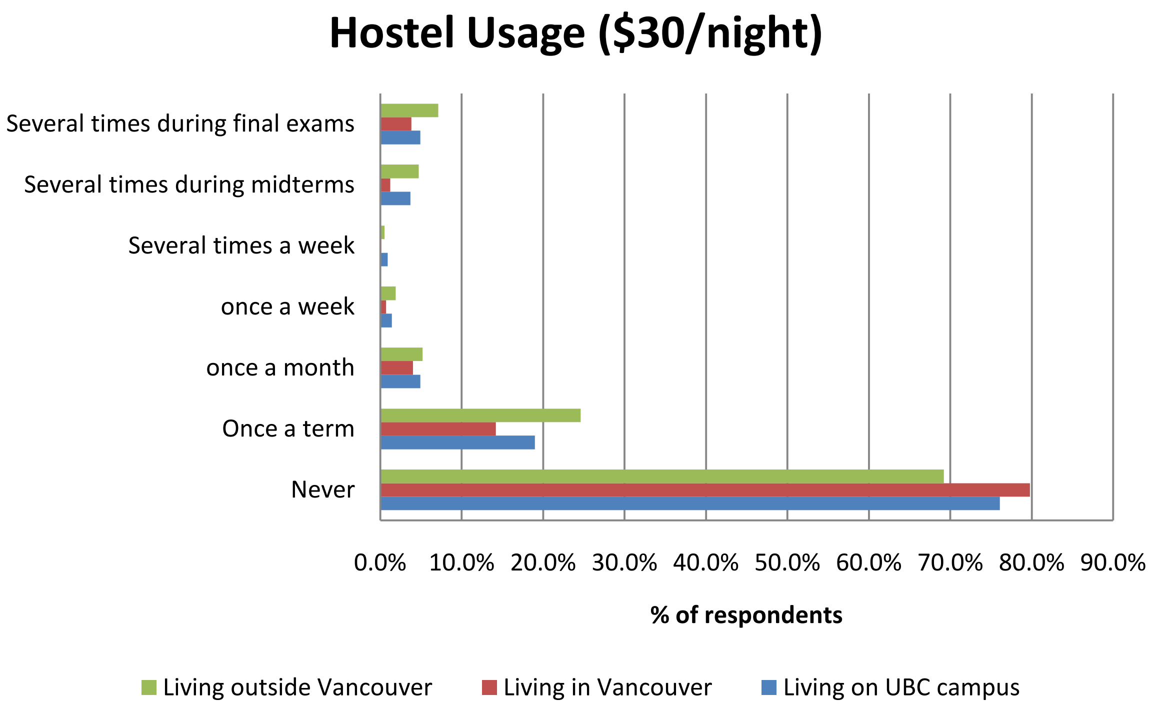
Majority of student are willing to pay 25 – 50 cents on a pay-by-day system and under $20 on a pay-by-term system.

Based on this response, the SUB Renewal Team has included a Phase 1 in the program as a pilot study with a limited number of lockers. Lockers can also be integrated under benches for small storage (e.g. backpacks). If the demand for the service is confirmed Phase 2 will be implemented with additional lockers added to secondary circulation corridors. No lockers will be added to main circulation corridors.

4.4 Hostel

A hostel service is proposed as a means to provide temporary lodging for students on campus. The following two graphs list the expressed usage of a hostel service if offered at $20/night and $30/night. The responses are separated by respondents living location.



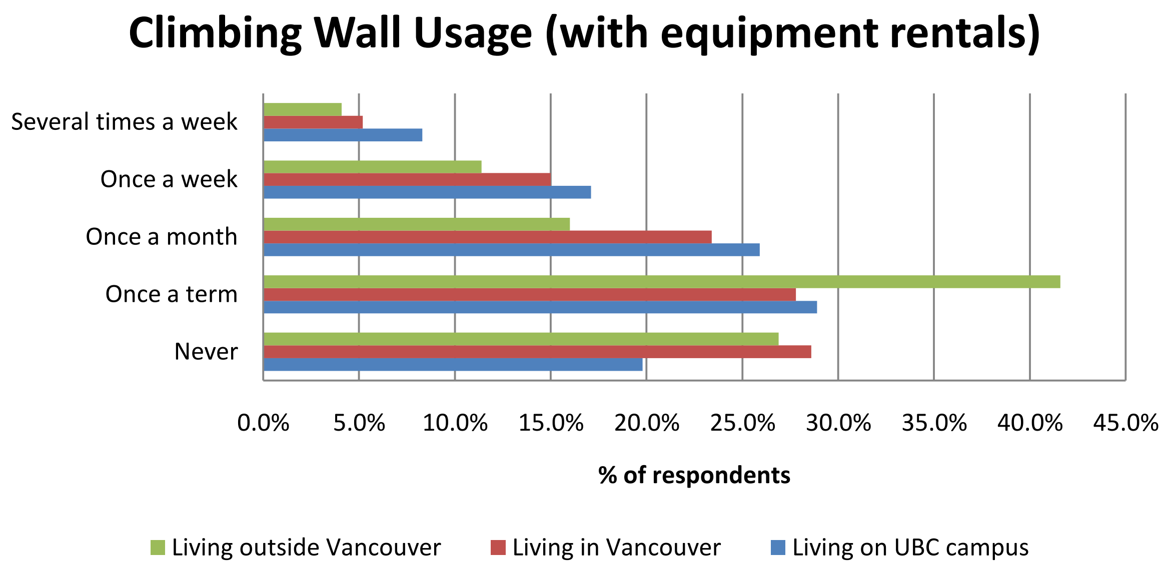


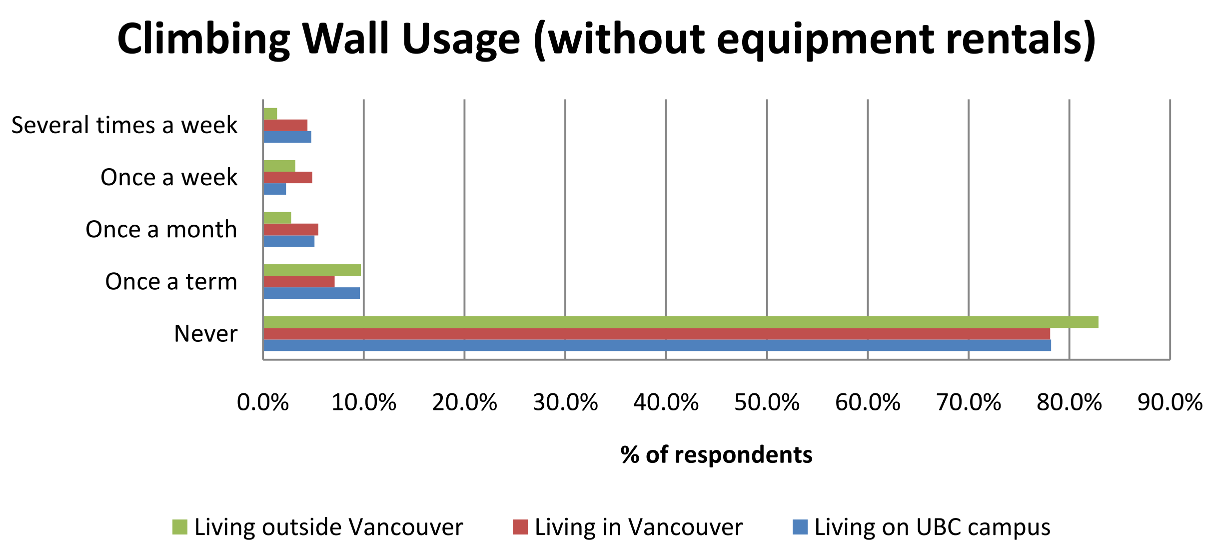
Respondents living outside of Vancouver show the most interest in a hostelling service but only at an affordable price; at $20/night there is a significant increase in expressed usage over $30/night. There is a high level of interest for this service to be offered during exam times, particularly among those living outside of Vancouver.

The SUB Renewal Team has concluded that a hostel service will not be added to the program but multi-functional space could be converted if need for this service deems it necessary. In addition, adding small storage lockers under benches could be used to store backpacks while students rest for a period of time.

4.5 Climbing Wall

A climbing wall is a feature intended to animate the main concourse space and encourage student interaction with one another in a fun environment. The following two graphs display the interest in a climbing wall based on two different management scheme: with equipment rentals available and without equipment rentals available. The responses are separated by respondents living location.

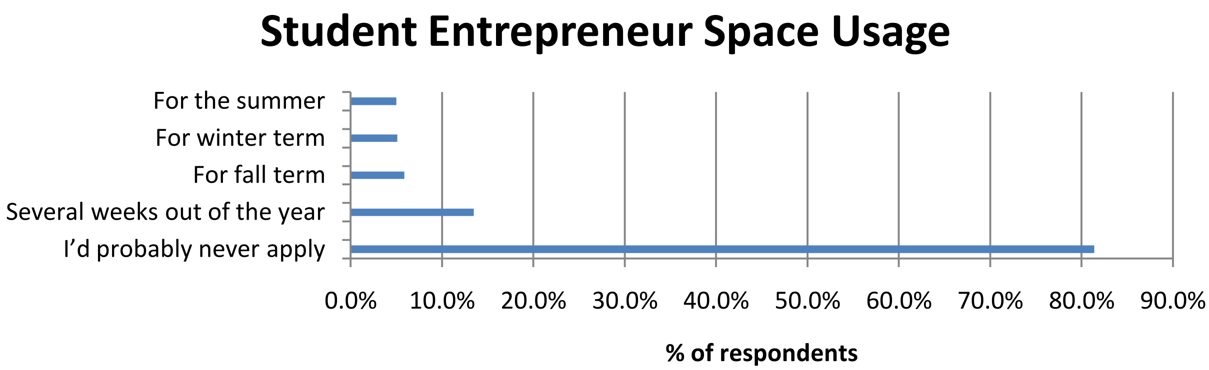




If equipment rentals are available there is a high level of interest among all three groups. Those living on UBC campus would be the most frequent users, followed by those living in Vancouver then those living outside of Vancouver. Without equipment rentals, however, there is very low interest, indicating that many more people will use the service than those who own climbing equipment. Based on this response a climbing has been added to the program.

4.6 Student Entrepreneur Space

A student entrepreneur space will allow business minded students to try out their specific business ideas on campus. The intention is that the space will open up students to the innovation of their peers and promote a vibrant and interactive student community. The following graph shows the interest in such a space.



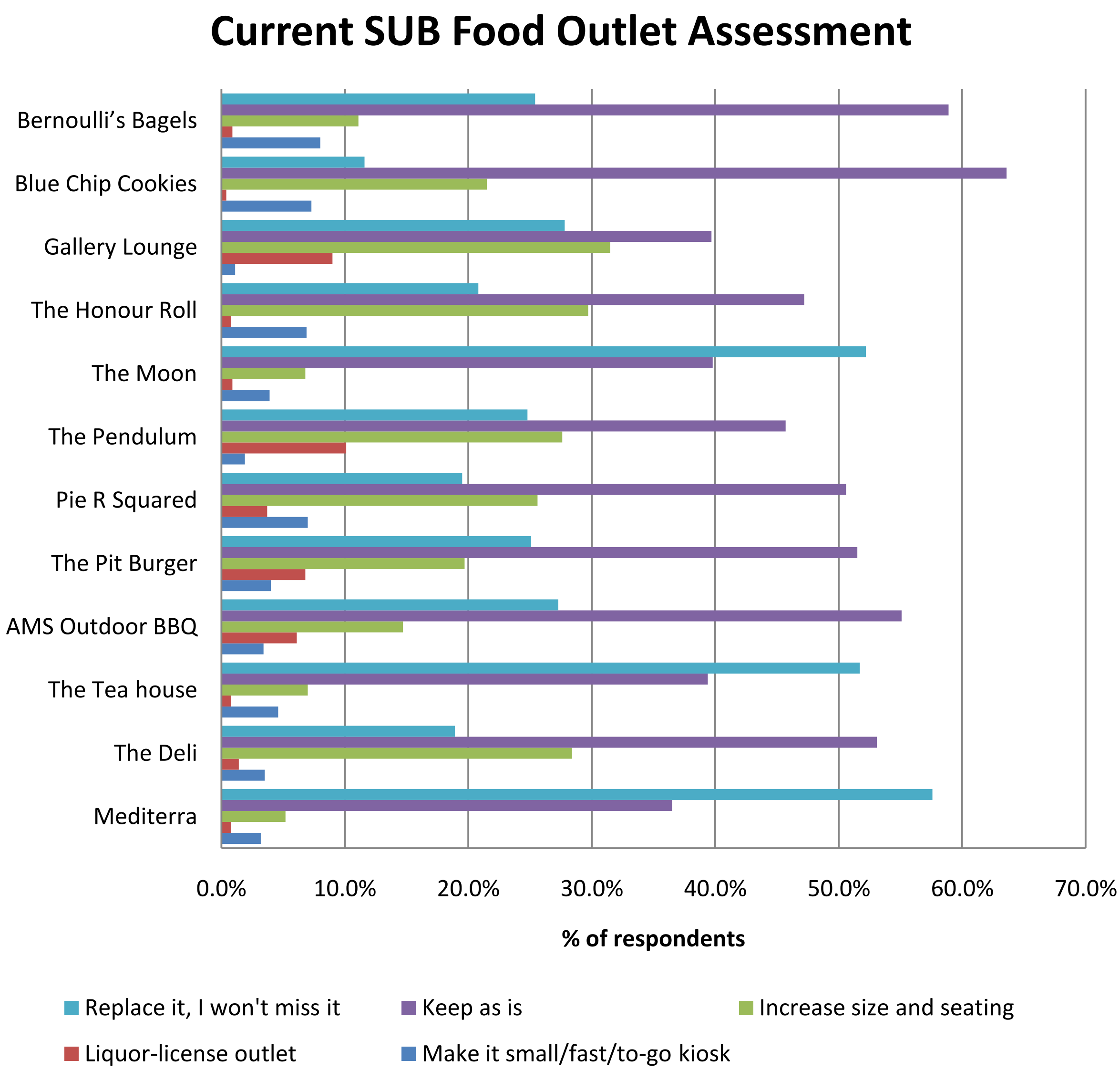
A very large majority of students would not apply; however, this highly specialized and limited service does not necessarily need to attract a lot of applicants. In fact, the low level of interest among most could mean that those interested will have a better chance at using the service. The SUB Renewal Team has concluded that space for this specific service will not be added to the program, however, one of the three tenant space can be converted if interest deems it necessary.

5.0 Food Services

This section aims to identify the food service needs of the student community and how improvements can be made over the current SUB's food services. Similar to Section 4.0, some responses have been analyzed according to respondents living locations in order to identify which specific food services are needed by residents of UBC campus and commuter students respectively.

5.1 Current Food Services

Respondents were asked to rate the current SUB's food outlets according to five categories: replace it/won't miss it, keep it as is, increase size and seating, liquor-license outlet, and make it small/fast/to-go kiosk. The intention of this question is to gauge student perception of the current SUB food outlet's ability to meet the community's food needs. The following graph and subsequent analysis shows the survey response for each of the current food outlets in the SUB.



The following sub-sections will summarize the survey findings on the current SUB food outlets.

5.1.1 Bernoulli's Bagels

The majority of respondents stated that Bernoulli's Bagels should be kept as is with as sizable response to replace it. This response indicates that there is a large number of students who use this outlet or at least see the value in it.

5.1.2 Blue Chip Cookies

Blue Chip Cookies had the highest percentage of respondents stating that it should say as is with just over 20% wanting an increase in size and seating. As this is the only food service in the AMS controlled portion of the current SUB that offers coffee, this response is not surprising.

5.1.3 Gallery Lounge

The Gallery Lounge had the most divided response among survey respondents with just fewer than 40% wanting to keep it as is. The high level of response for both replacing the Gallery Lounge and to increase the size indicates that there is a split opinion among the Gallery's ability to serve the student community: with some favouring the current organization of the outlet but wanting more seating, and others wanting a change in organization. Conversely, since the Gallery is primarily a liquor establishment, the high level of response for replacing it could be attributed to whether respondents drink alcohol. Also refer to the Graduate Student Survey Summary for further information on the need for liquor establishments.

5.1.4 The Honour Roll

A large percentage of respondents stated that The Honour Roll should either be kept as is or increased in size and seating.

5.1.5 The Moon

A majority of respondents stated that The Moon should be replaced with just fewer than 40% stating that it should be kept as is. With sizable percentage of respondents wanting to keep this outlet as it, even with a majority of students wanting to replace it, could mean that the outlet is meeting the needs of a segment of the student population.

5.1.6 The Pendulum

A large percentage of respondents stated that The Pendulum should either be kept as is or increased in size and seating. Nearly 10% of respondents stated that The Pendulum should be liquor-licensed, which represents the highest response for this selection.

5.1.7 Pie R Squared

Just over a majority of respondents stated that Pie R Squared should be kept as is while roughly 1/4 stated that it should be increased in size and seating.

5.1.8 The Burger Pit

Just over a majority of respondents stated The Burger Pit should be kept as is while roughly 1/4 stated that it should be replaced. There just fewer than 20% of respondents who wanted an increase in size and seating.

5.1.9 AMS Outdoor BBQ

The majority of respondents stated that the AMS Outdoor BBQ should be kept as is with over 1/4 stating it should be replaced.

5.1.10 The Tea House

Just over a majority of respondents stated that The Tea house should be replaced, however with just under 40% stated that it should be kept as is indicates an sizable interest in the establishment. There are currently two similar establishment serving bubble tea as well as other Asian foods has opened in the village (east of Westbrook Mall on University Boulevard), one just opened in winter 2008, which may increase the competition and decrease market share.

5.1.11 The Deli

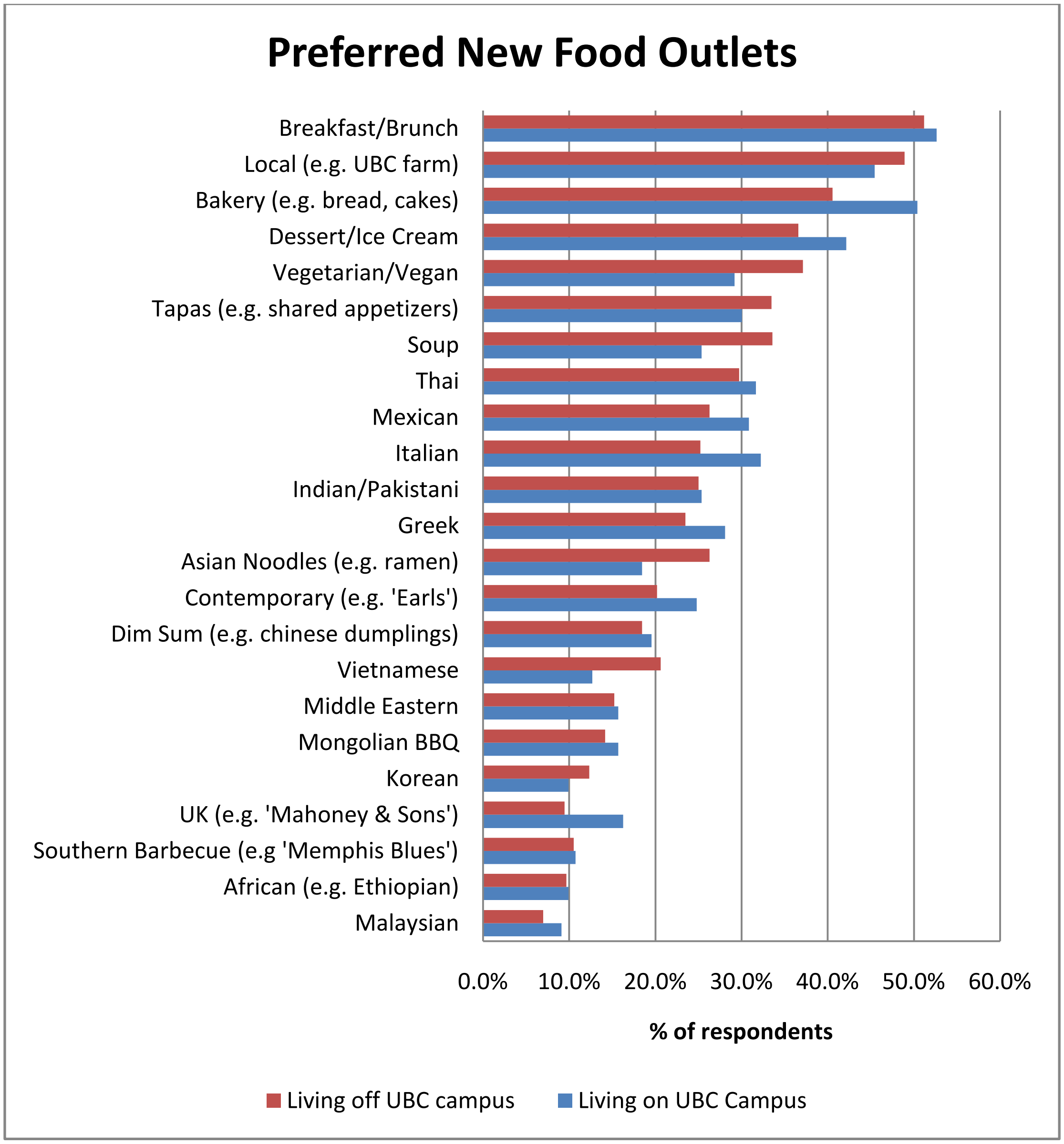
The majority of respondents stated that The Deli should be kept as is with a sizable percent of respondents wanting an increase in size and seating.

5.1.12 Mediterra

The Mediterra had the highest percent of respondents stating that it should be replaced, over 55%. Just over 35% stated that it should be kept as is and roughly 5% wanted an increase in size and seating. This outlet had least interest among of support among survey respondents; however, since this outlet is a recent addition, interest may take time to grow.

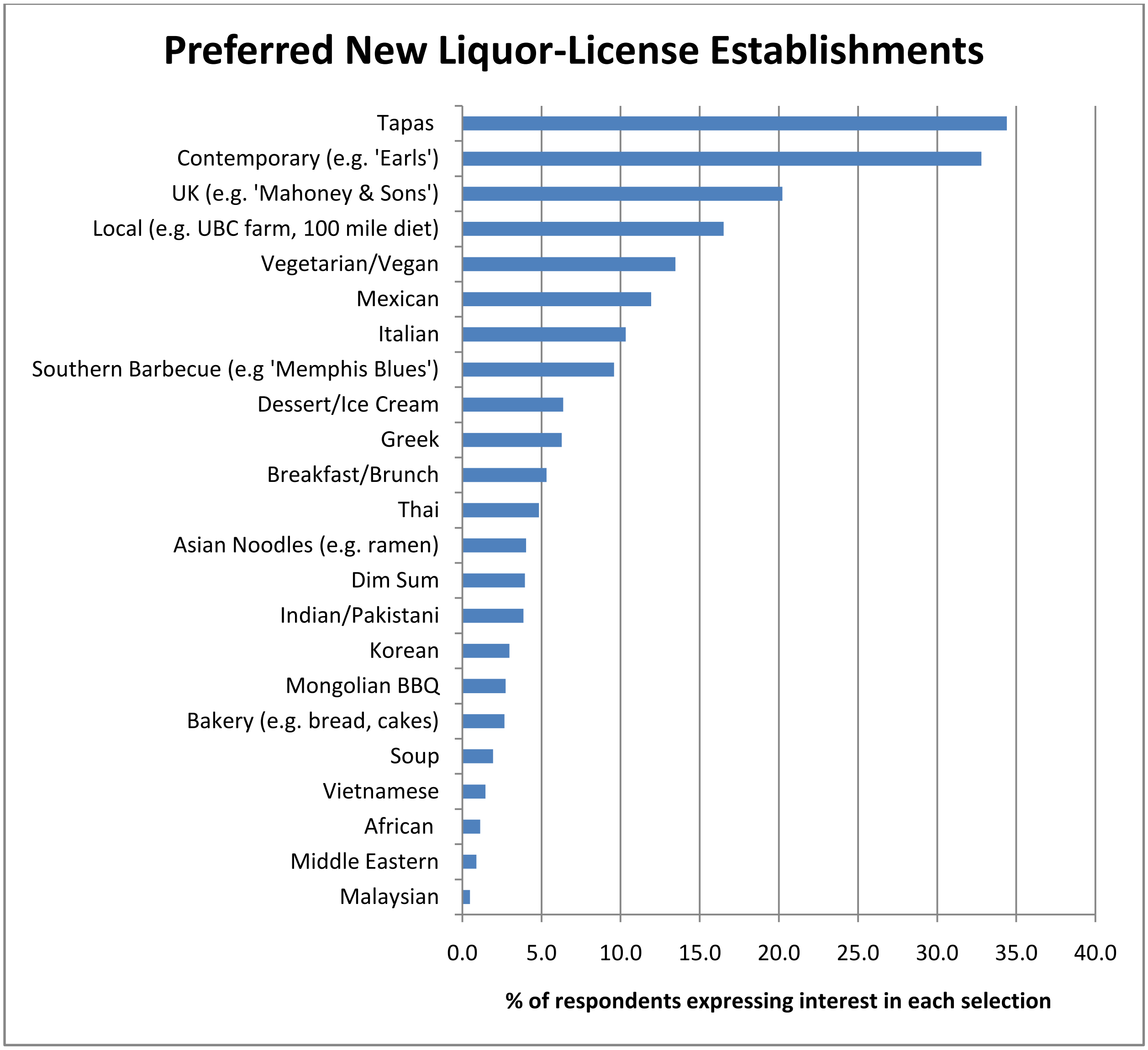
5.2 New Food Outlets

The New SUB provides an opportunity to better meet the food and nutrition needs of the UBC student community. The survey listed a number of potential new food outlets to determine what is most needed by students. The following displays the support of each of the new food outlet ideas in descending order and separated by respondents living location.

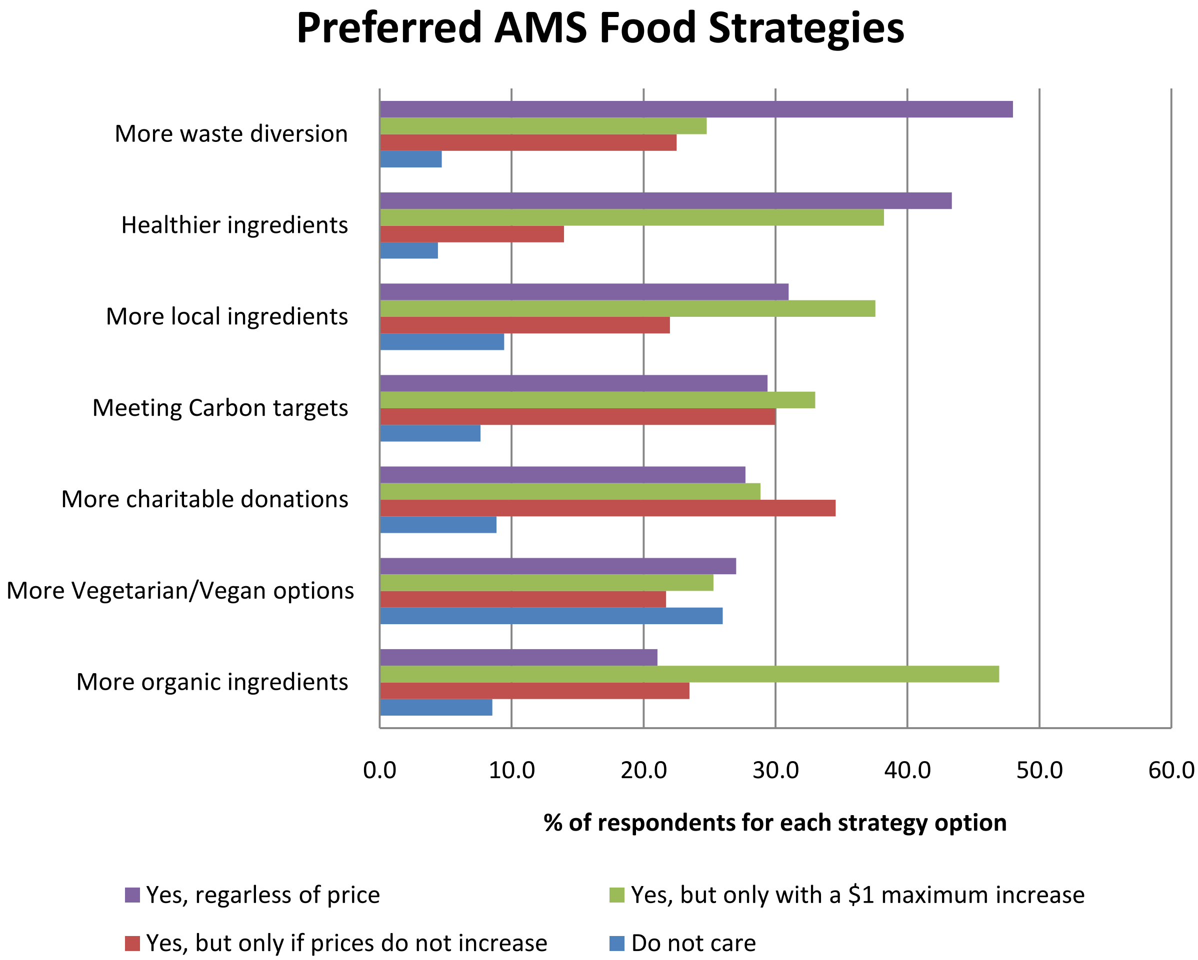


Of all the new food ideas, a breakfast outlet had the highest and most consistent support among all categories of respondents. The remaining new food ideas showed some break in preference among those respondents living on UBC campus and those living off campus. For those living on UBC campus, a bakery and desert outlet had high support. This is consistent with the notion that those living on campus are in need of food outlets that work in conjunction with their own kitchens/food plans as oppose to meal outlets. Those living off campus indicate high support for a food outlet serving local food.

Respondents were then asked which new food outlets should be liquor-licensed. The following graph indicates the support for liquor-licensed locations in descending order.



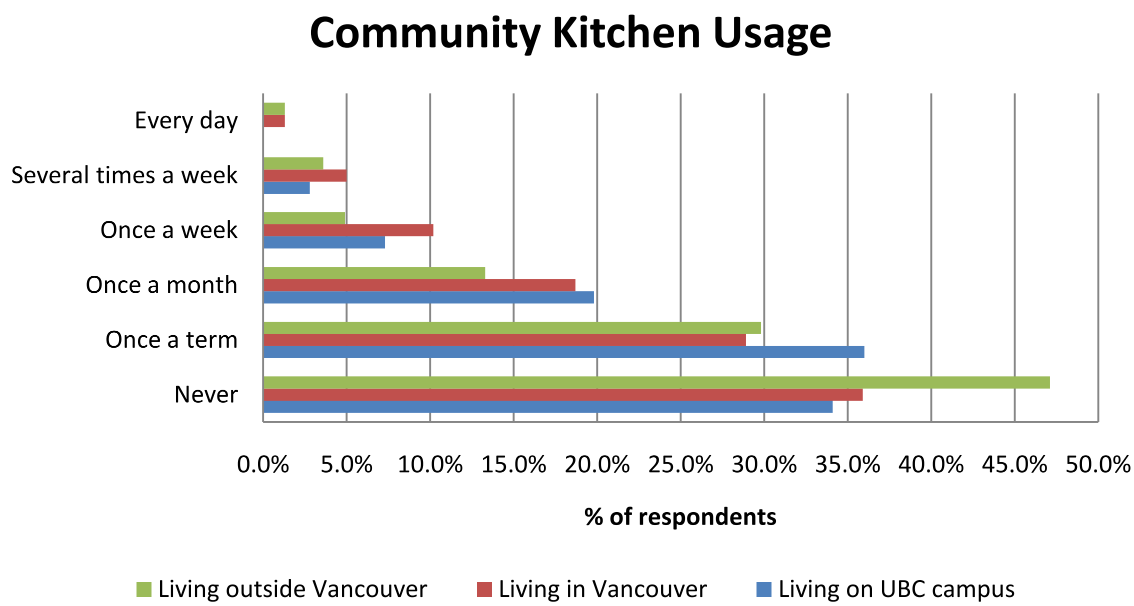
The following graph displays the response to what areas the AMS should be concentrating on when developing a new food outlet policy.



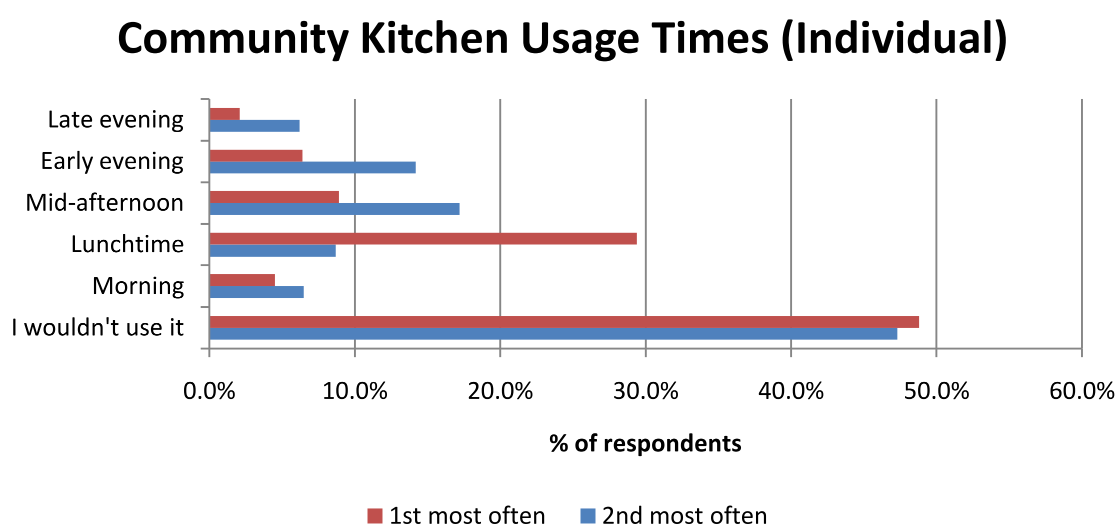
There were a sizable number of respondents who indicated the importance of waste diversion and healthier ingredients in AMS food policy, regardless of the affect on the price of food. Using more organic ingredients and more local ingredients were supported as long as it did not increase the price of food by more than $1 or 5-10%. Charitable donations were supported as long as there is no increase in food prices.

5.3 Community Kitchen

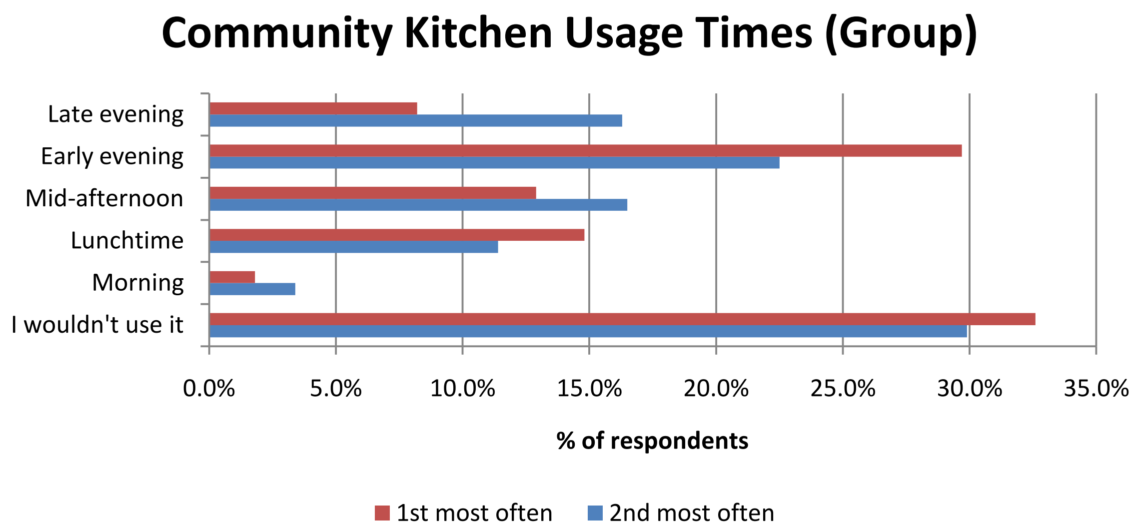
A community kitchen is intended to provide students and clubs a full kitchen to prepare meals. The following graphs display the survey response to the interest in using the community kitchen, the preferred times to use the kitchen, and the preferred management of the kitchen.

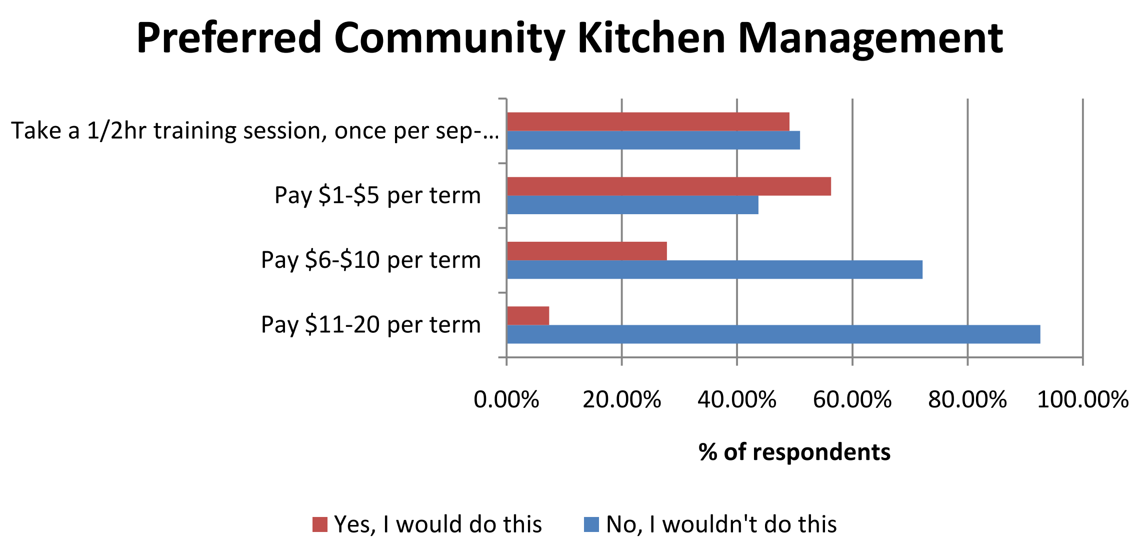


Community Kitchen Usage
Every day
Several times a week
Once a week
Once a month
Once a term
Never
0.0%
5.0%
10.0%
15.0%
20.0%
25.0%
30.0%
35.0%
40.0%
45.0%
50.0%
% of respondents
Living outside Vancouver
Living in Vancouver
Living on UBC campus



Community Kitchen Usage Times (Individual)
Late evening
Early evening
Mid-afternoon
Lunchtime
Morning
I wouldn't use it
0.0%
10.0%
20.0%
30.0%
40.0%
50.0%
60.0%
% of respondents
1st most often
2nd most often

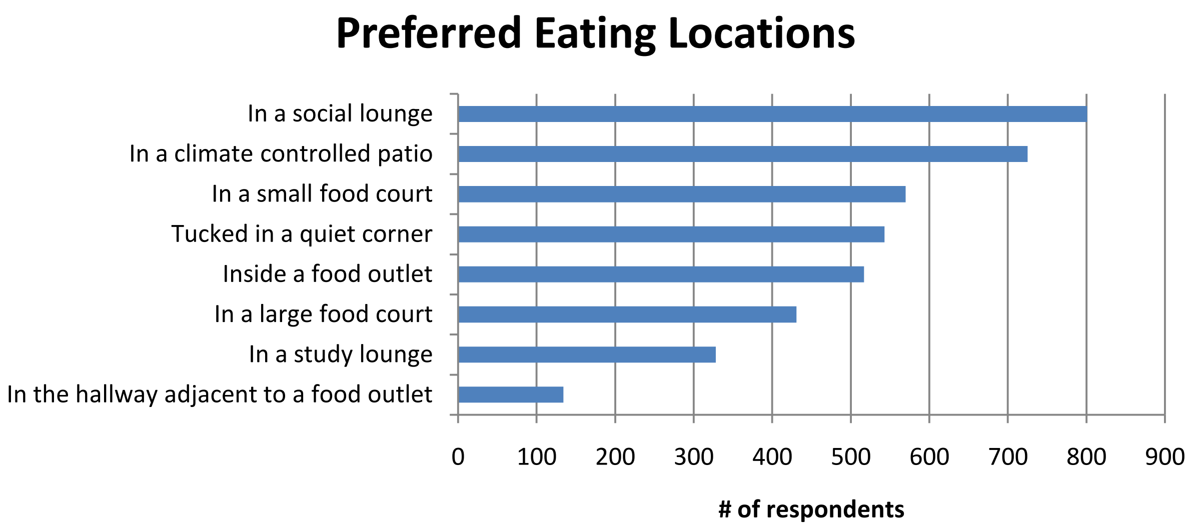


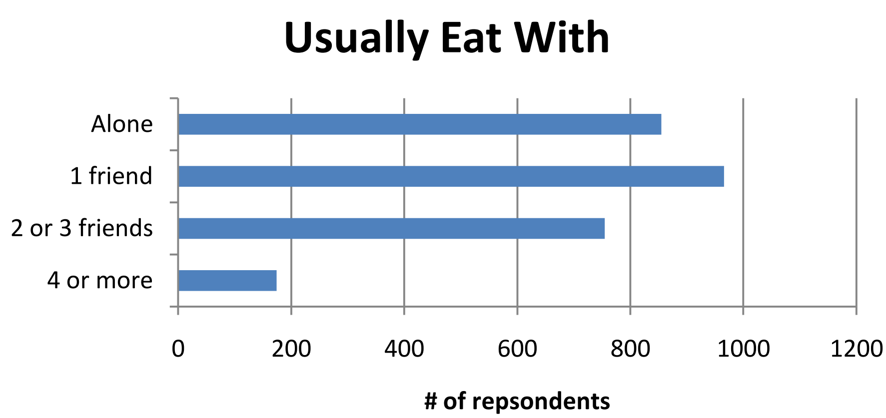


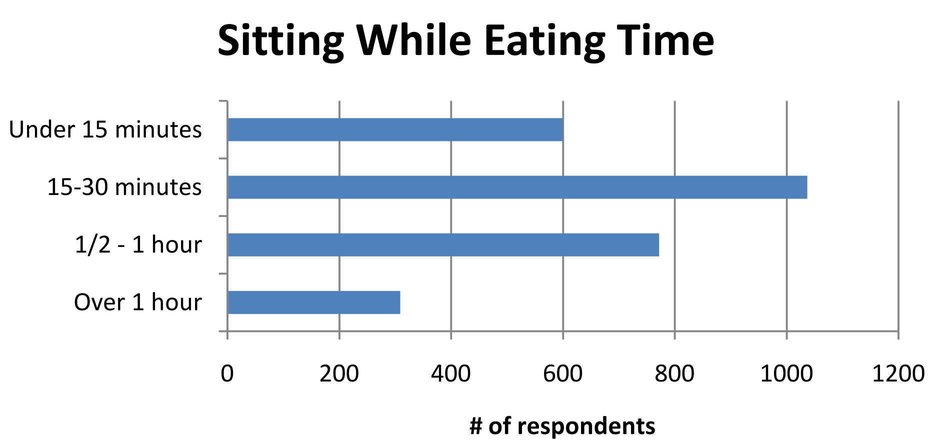
Based on this response a community kitchen has been added to the program with the capacity for 6-12 people maximum. The kitchen will most likely operate during lunch and into the early evening with clubs able to book special times, however, operation will be refined once the need has been confirmed.

5.4 Student Eating Habits

The following three graphs indicate the eating habits of the survey respondents.







The results from these questions indicate that the majority of respondents prefer eating in social lounges with space for 2 to 3 people as well as several spaces for individuals. It needs to be noted that the survey responses may be negatively influenced by the current SUB configuration and that responses may be affected by exposure to different environments, such as better designed seating in food outlets.

Appendix B Detailed Parts & Assembly Drawings

B1. Wall Assembly

B2. Vertical Column

B3. Corner Brackets

B4. Horizontal Column

B5. Anchor brackets

B6. Bottom Column

B7. Bottom Reservoir

B8. Capillary Mat

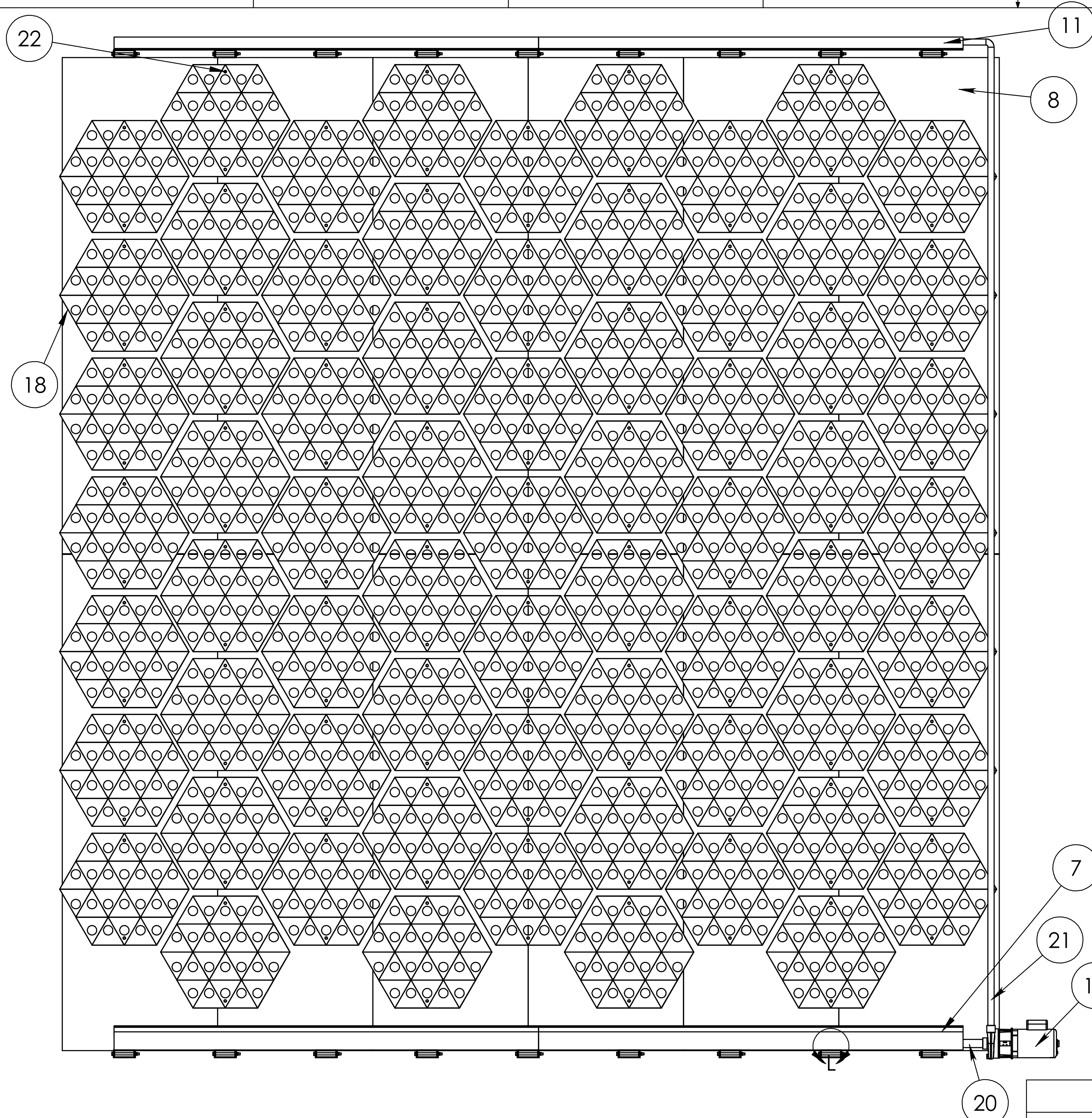
B9. Plastic Laminar

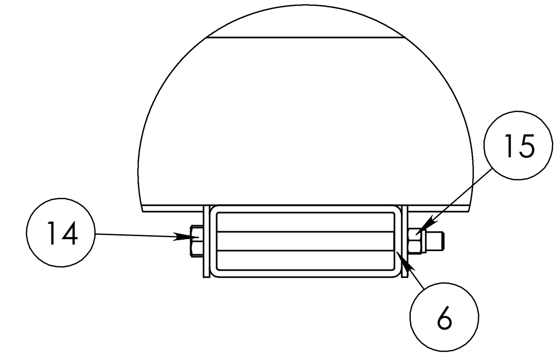
B10. Connecting Brackets

B11. Upper Reservoir

B12. T-brackets

B13. Cell Unit





DETAIL L
SCALE 1 : 4

ITEM NO.	PART NUMBER	DESCRIPTION	QTY.
1	Vertical Column		18
2	Corner brackets		98
3	Horizontal Column		49
4	Anchor brackets		36
5	Anchor bolt		36
6	Bottom Column		18
7	Bottom Reservoir (Leafproof)		2
8	Capillary Mat		12
9	Plastic laminar		12
10	Connecting Brackets		18
11	Upper Reservoir		2
12	T-brackets		36
13	Wall anchor washer	17-4 PH Stainless Steel, 1/4"	1
14	3/8"-16 Hex Bolt	17-4 PH Stainless Steel, 5 inch in length	216
15	3/8" Hex Nut	18-8 Stainless Steel	446
16	Bracket Bolt Washer	17-4 PH Stainless steel, 3/8"	96
17	3/8" -16 Hex Bolt	17.4 PH Stainless Steel, 2 inch in length	96
18	Living Wall Cell Unit		67
19	Centrifugal Pump	4.7 gpm at 60 feet of head	1
20	Parallel Piping	ABS,OD 1.2 inch	1
21	Upward Piping	ABS,OD 1.6 Inch	1
22	bolt 3 in		134

NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ± 1/16
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Wen Li	Jan 28
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

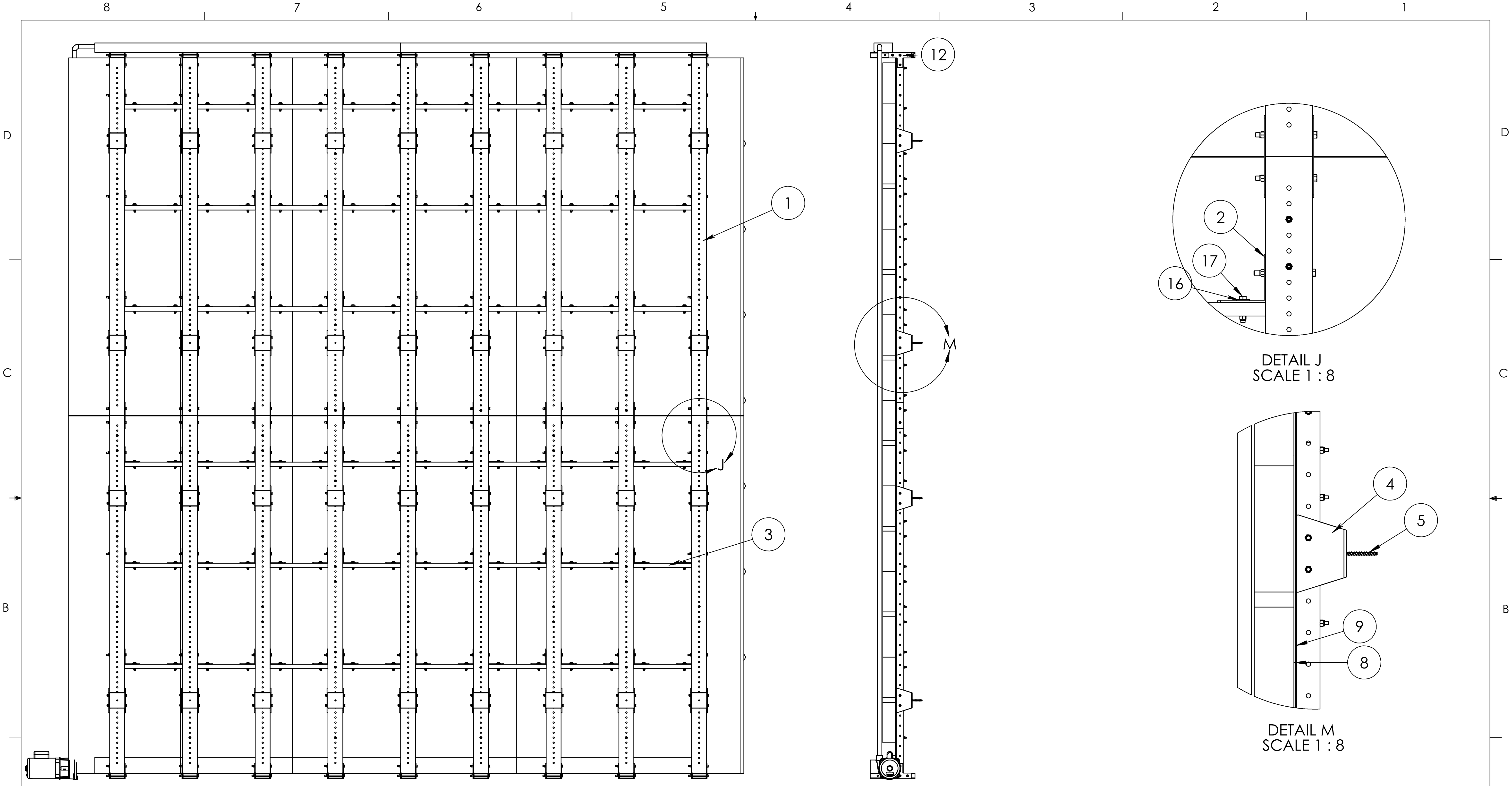
COMMENTS:

TITLE:

Living Wall Assembly

SIZE **B** | DWG. NO. | REV 4

SCALE: 1:30 | WEIGHT: | SHEET 1 OF 2



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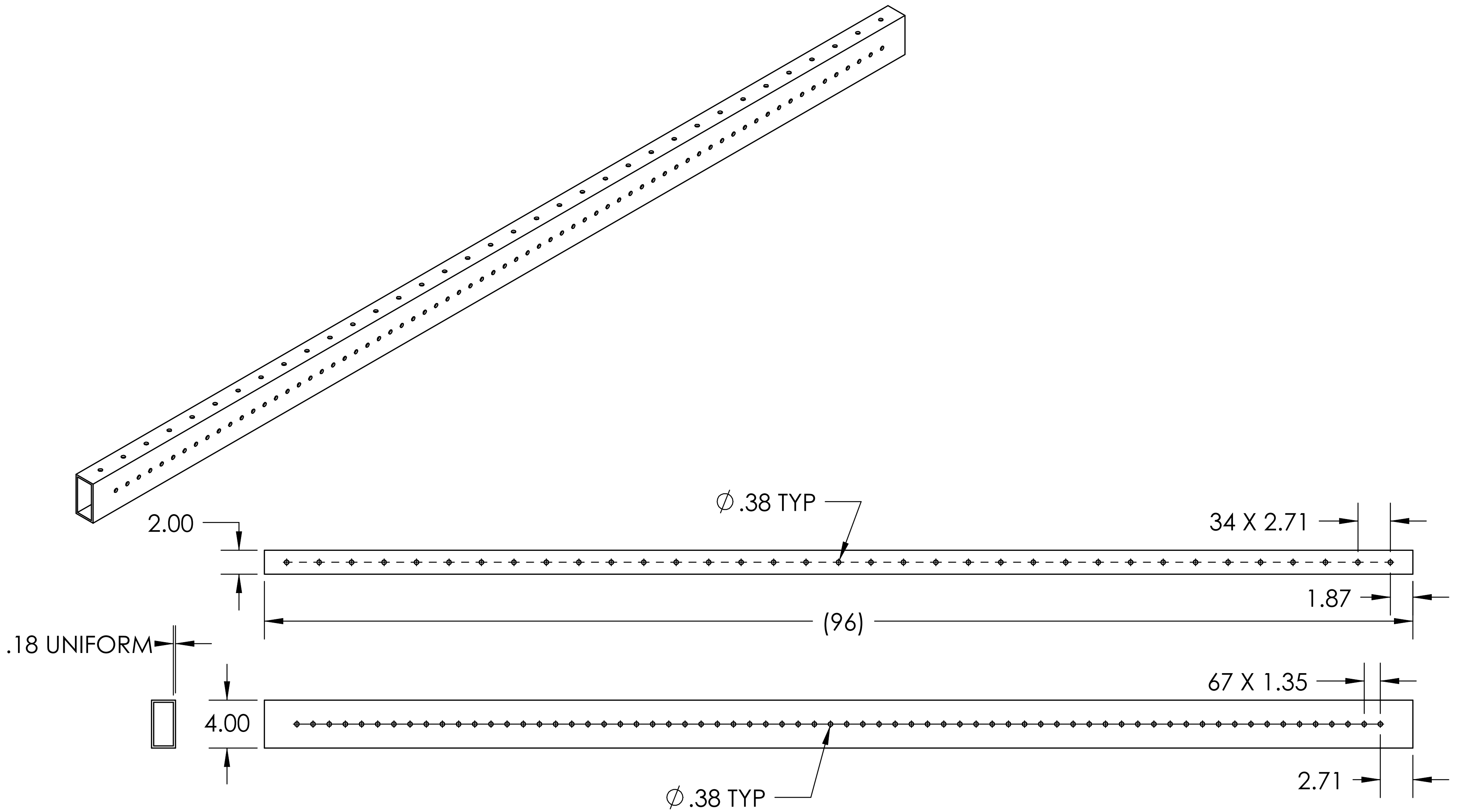
NEXT ASSY	USED ON	UNLESS OTHERWISE SPECIFIED:		NAME	DATE
APPLICATION		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL±1/16 TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	DRAWN	Wen Li	Jan 28
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
		FINISH			
		DO NOT SCALE DRAWING			

TITLE:

Living Wall Assembly

SIZE	DWG. NO.	REV
B		4
SCALE:1:30	WEIGHT:	SHEET 2 OF 2



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Wen Li	Jan 29
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

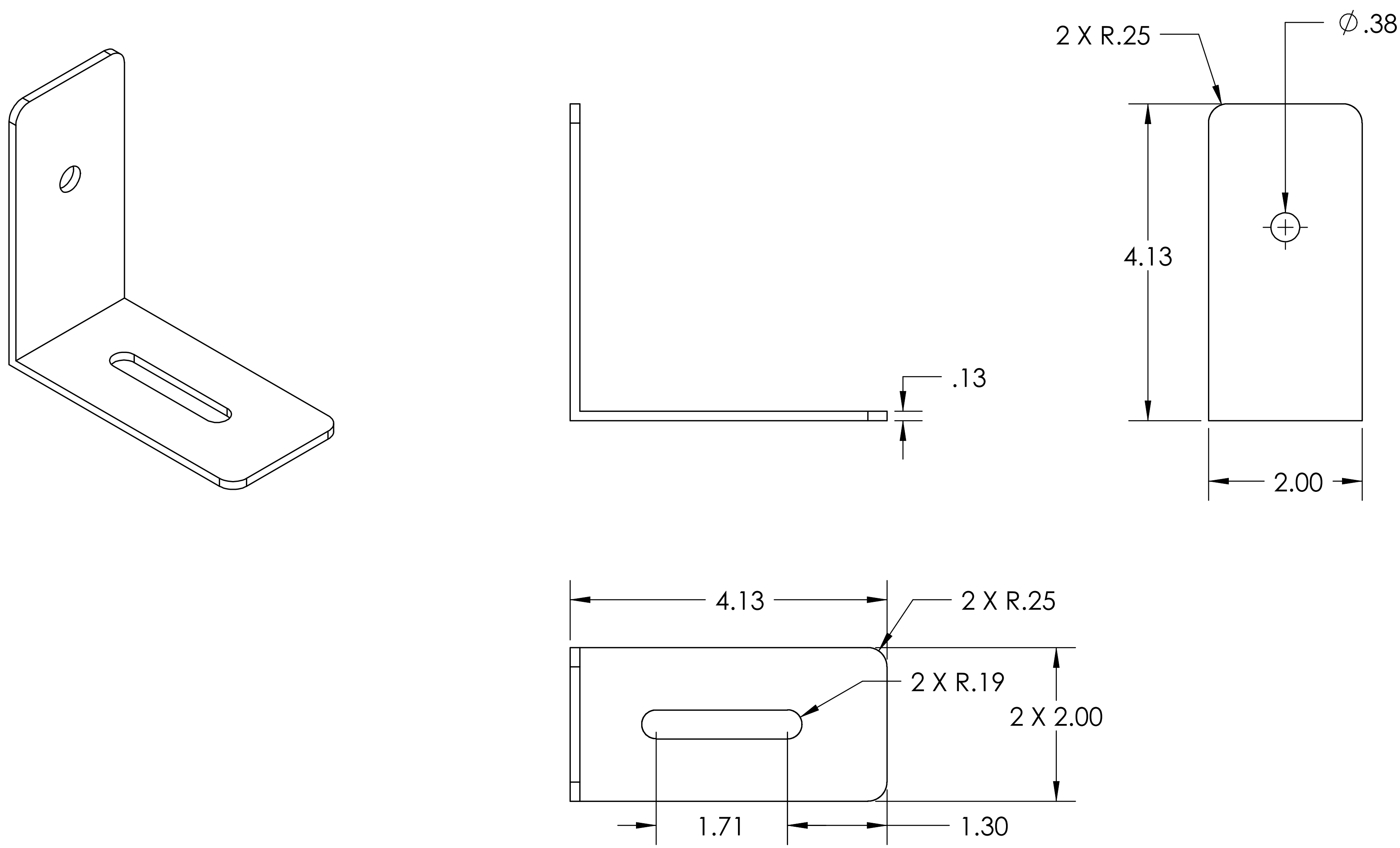
TITLE:

Vertical Column (8 ft)

SIZE	DWG. NO.	REV
A		2

SCALE:1:12 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
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			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

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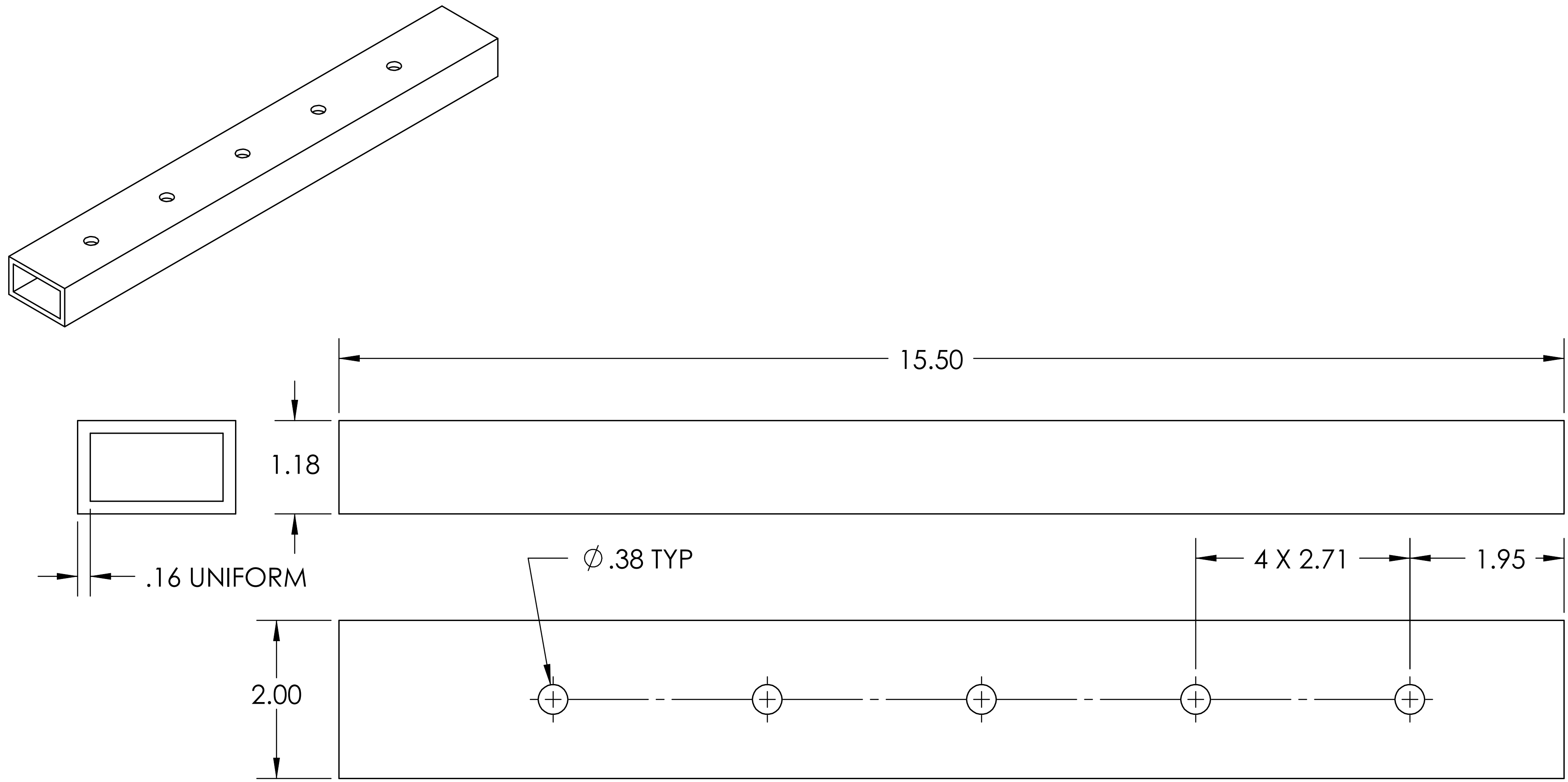
TITLE:

Corner Bracket

SIZE	DWG. NO.	REV
A		2

SCALE: 1:2	WEIGHT:	SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/16 TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	DRAWN	Wen Li	Jan 29
			CHECKED		
			ENG APPR.		
			MFG APPR.		
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.		
		MATERIAL	COMMENTS:		
NEXT ASSY	USED ON	FINISH			
APPLICATION		DO NOT SCALE DRAWING			

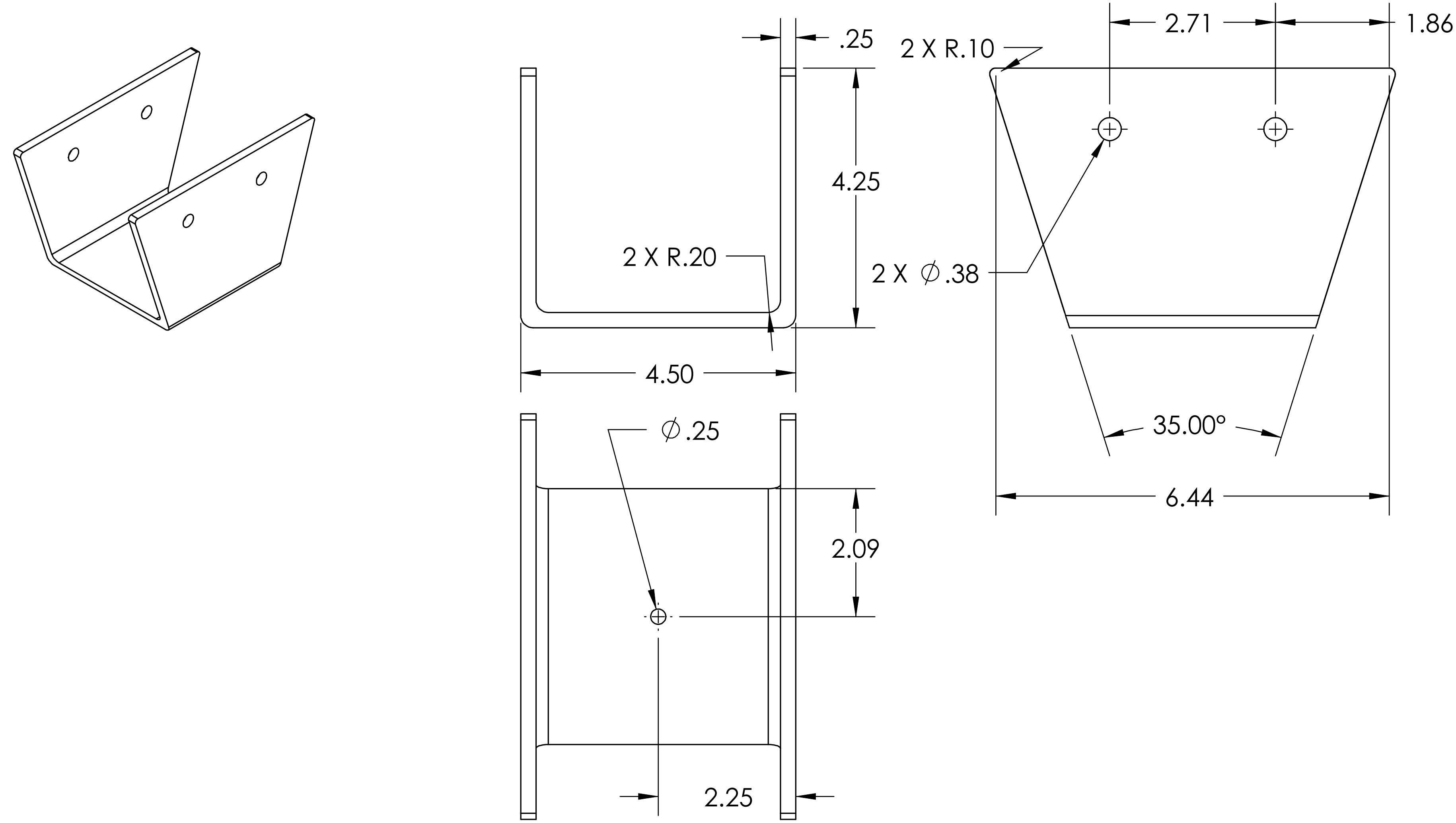
TITLE:

Horizontal Column

SIZE	DWG. NO.	REV
A		2

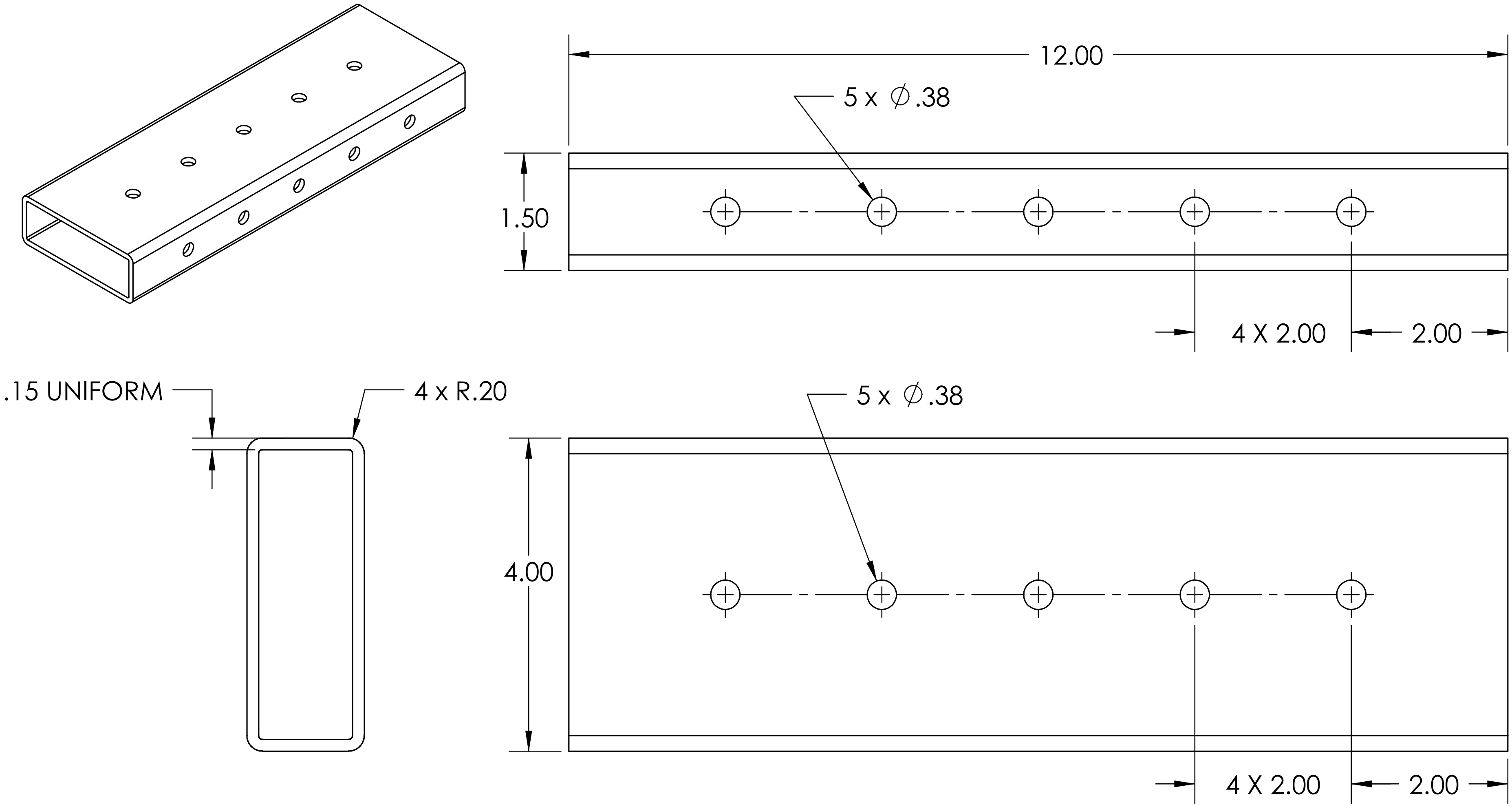
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL ±1/16 TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	DRAWN	Wen Li	Jan 29	TITLE:
			CHECKED			Anchor Bracket
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A · DWG. NO. · REV 2
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2.5 · WEIGHT: · SHEET 1 OF 1

5 4 3 2 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Wen Li	Jan 29
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

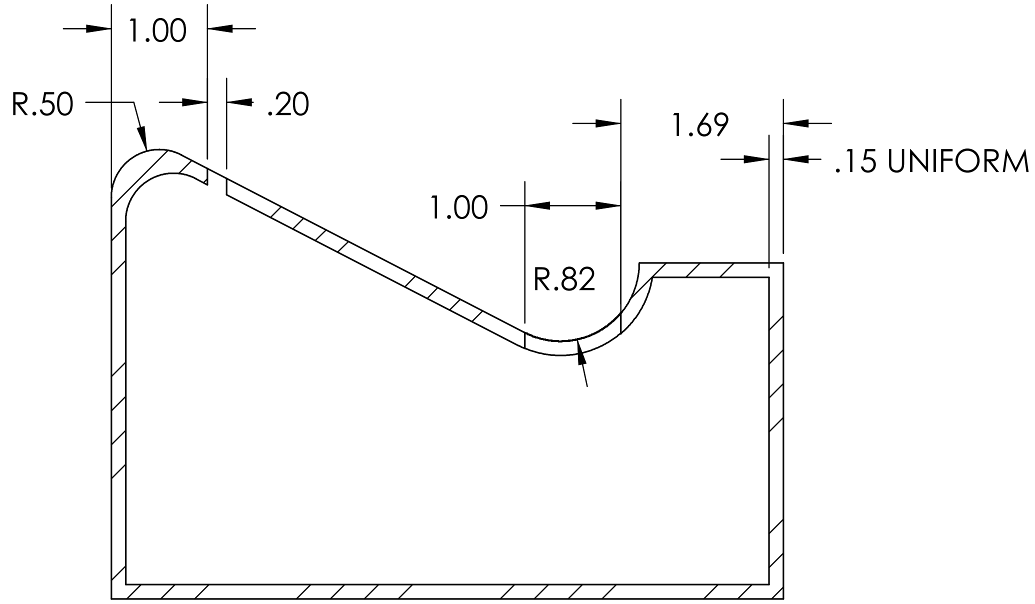
TITLE:

Bottom Column

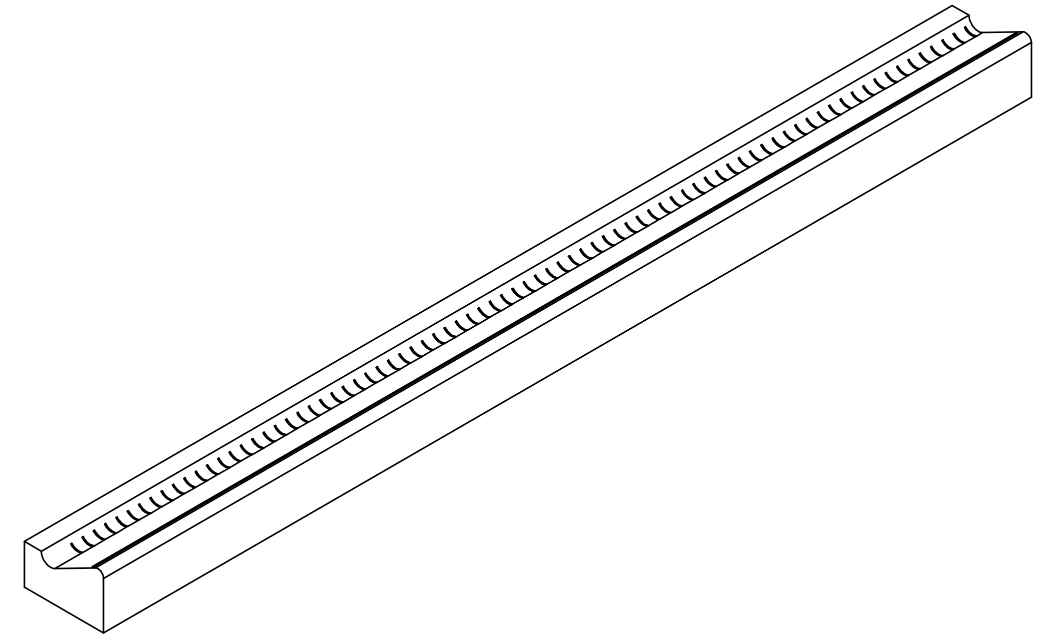
SIZE	DWG. NO.	REV
A		2

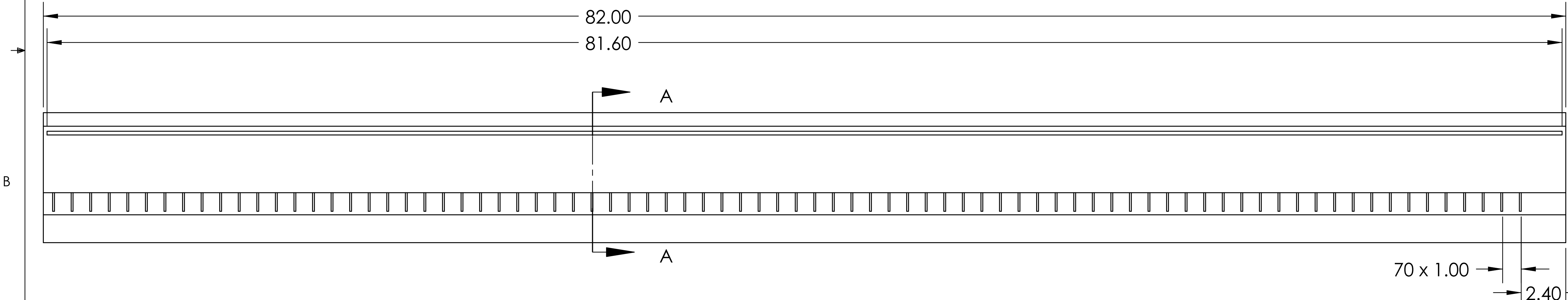
SCALE: 1:2 WEIGHT: SHEET 1 OF 1

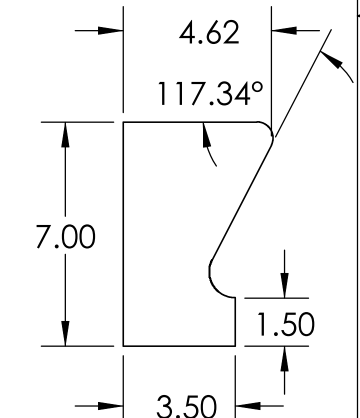
5 4 3 2 1



SECTION A-A
SCALE 1 : 2







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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL High density PE
FINISH
DO NOT SCALE DRAWING

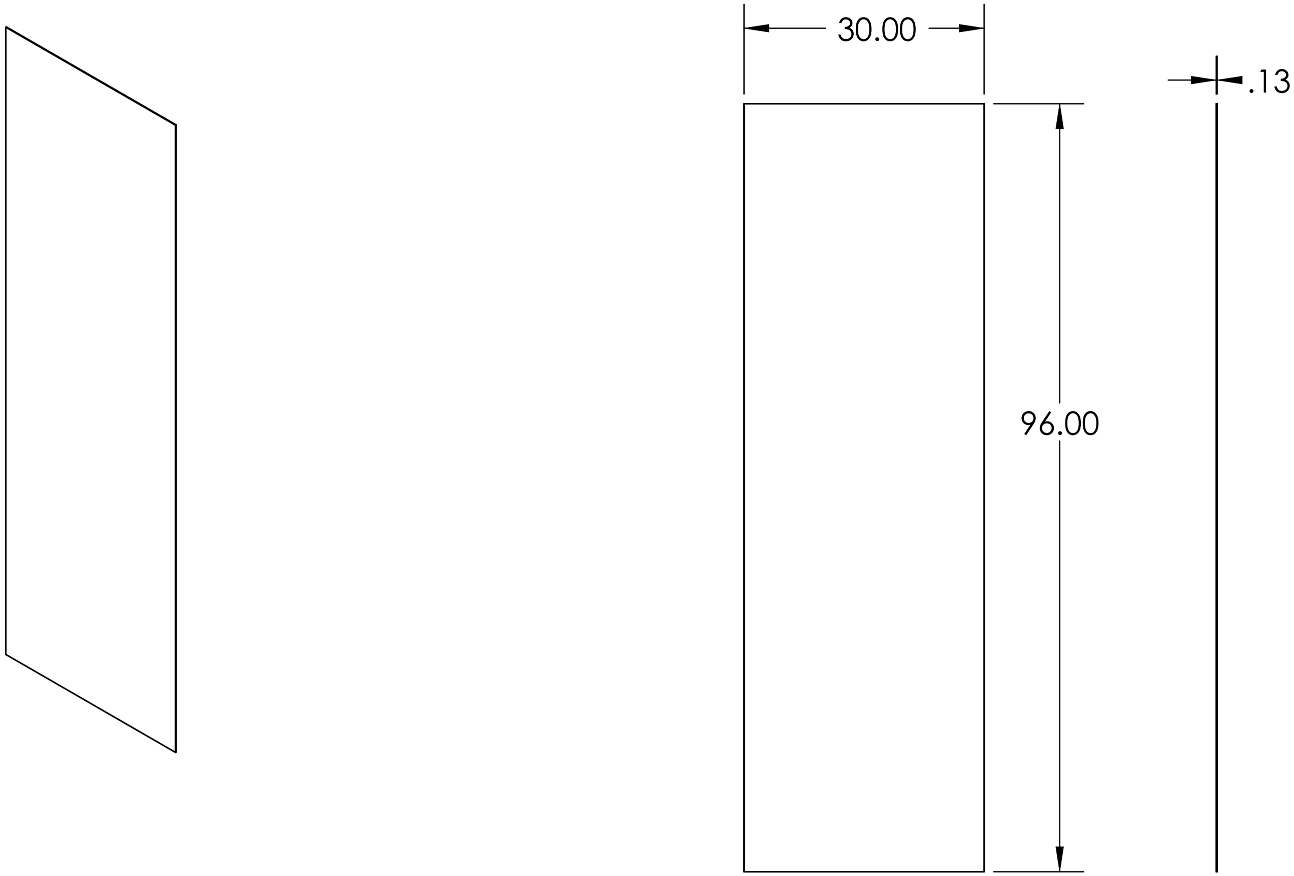
	NAME	DATE
DRAWN	Wen Li	Jan 29
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Bottom Reservoir

SIZE	DWG. NO.	REV
B		2

SCALE: 1:6	WEIGHT:	SHEET 1 OF 1

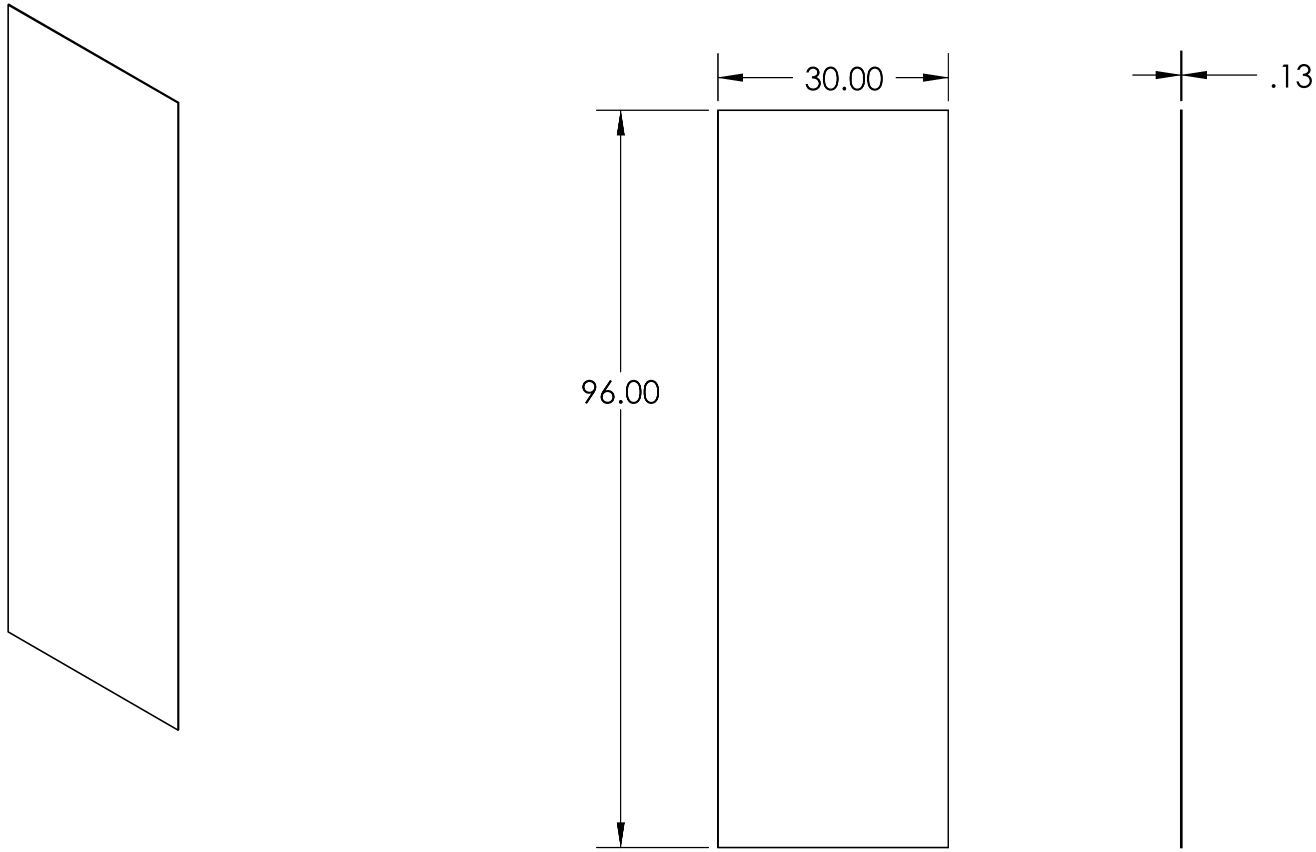


UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL±1/16 TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	DRAWN	Wen Li	Jan 29	
	CHECKED			TITLE:
	ENG APPR.			Capillary Mat
	MFG APPR.			
INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
MATERIAL Synthetic Fiber	COMMENTS:			SIZE A · DWG. NO. · REV 2
FINISH				
DO NOT SCALE DRAWING				SCALE: 1:24 · WEIGHT: · SHEET 1 OF 1

NEXT ASSY	USED ON
APPLICATION	

PROPRIETARY AND CONFIDENTIAL

5 4 3 2 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL ACRYLIC

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Wen Li	Jan 29
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

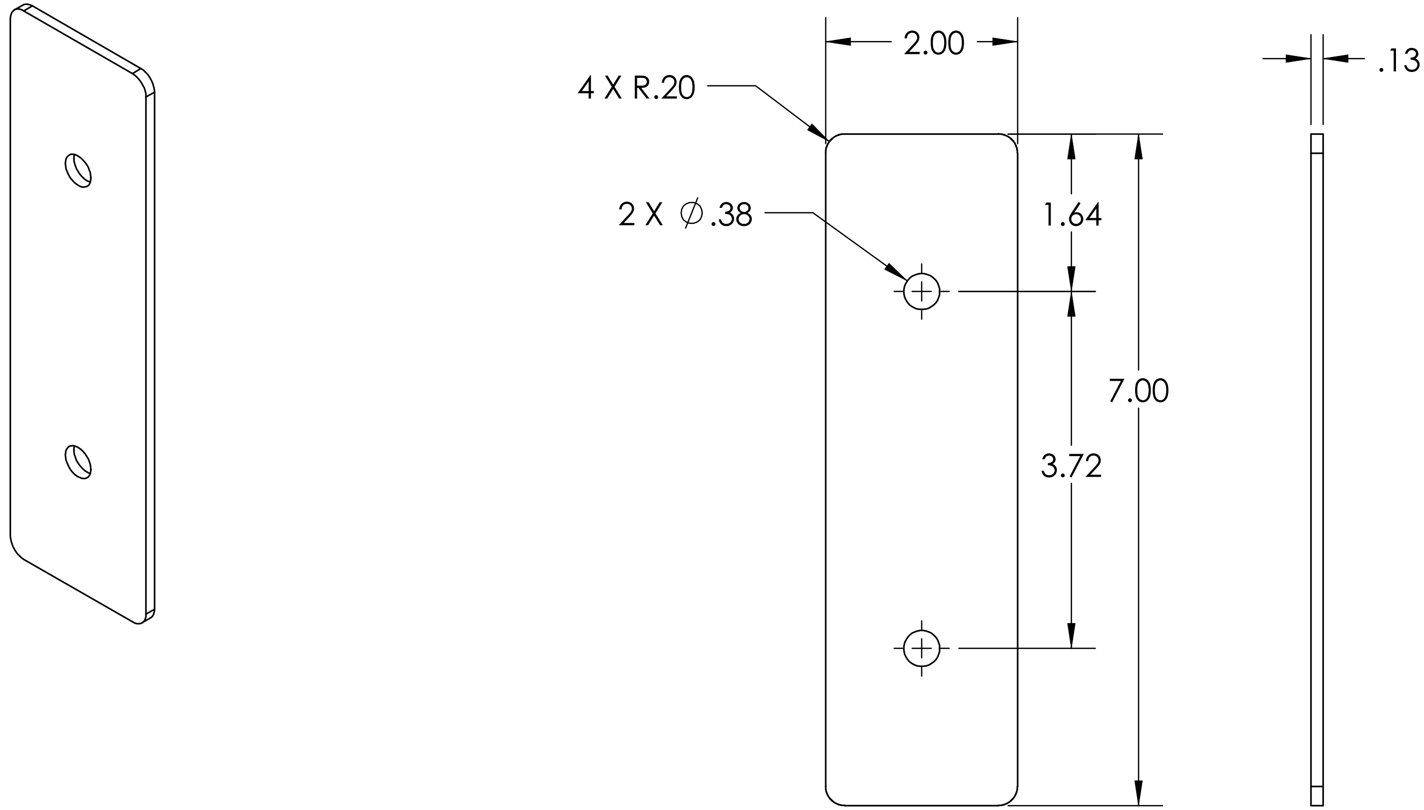
TITLE:

Plastic Laminar

SIZE	DWG. NO.	REV
A		1

SCALE: 1:25 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Wen Li	Jan 29
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

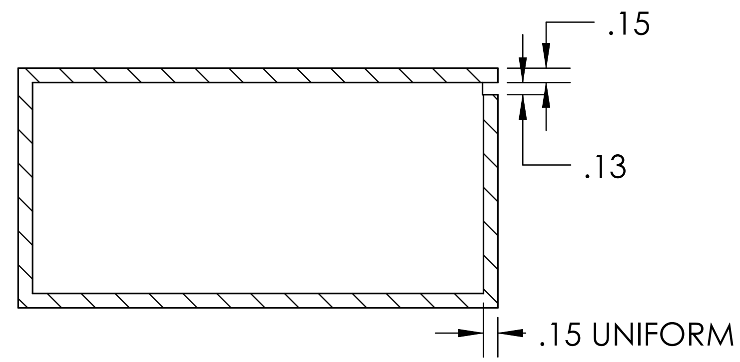
TITLE:

Connecting Bracket

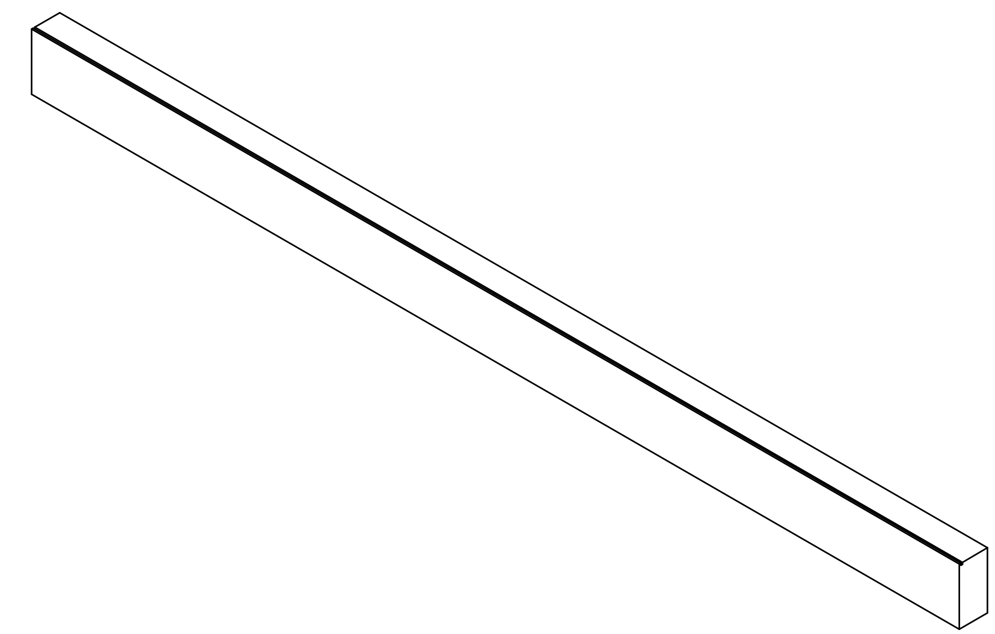
SIZE A | DWG. NO. | REV 1

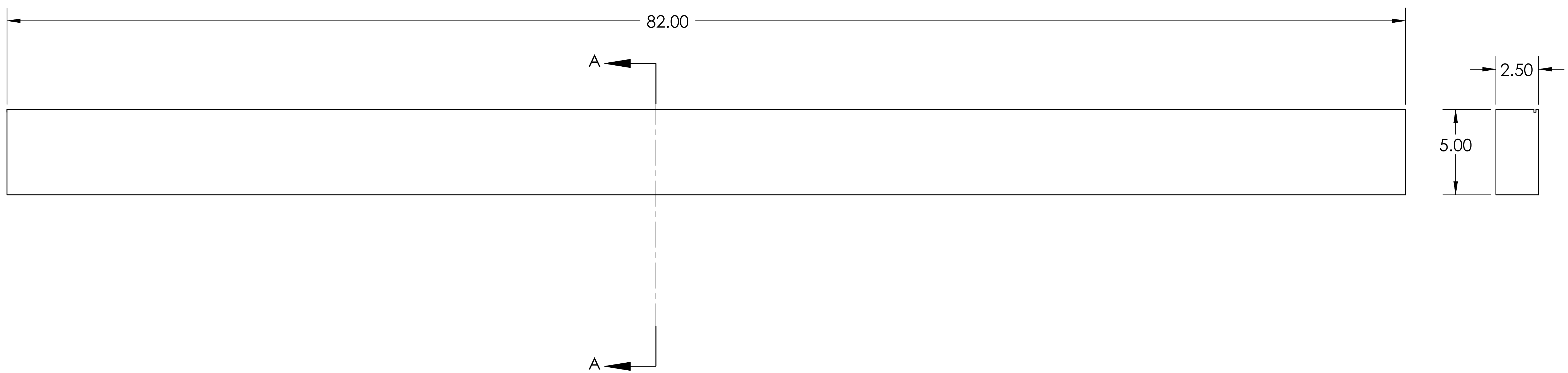
SCALE: 1:2 | WEIGHT: | SHEET 1 OF 1

5 4 3 2 1



SECTION A-A
SCALE 1 : 2





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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL ±1/16
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL High Density PE

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Wen Li	Jan 29
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

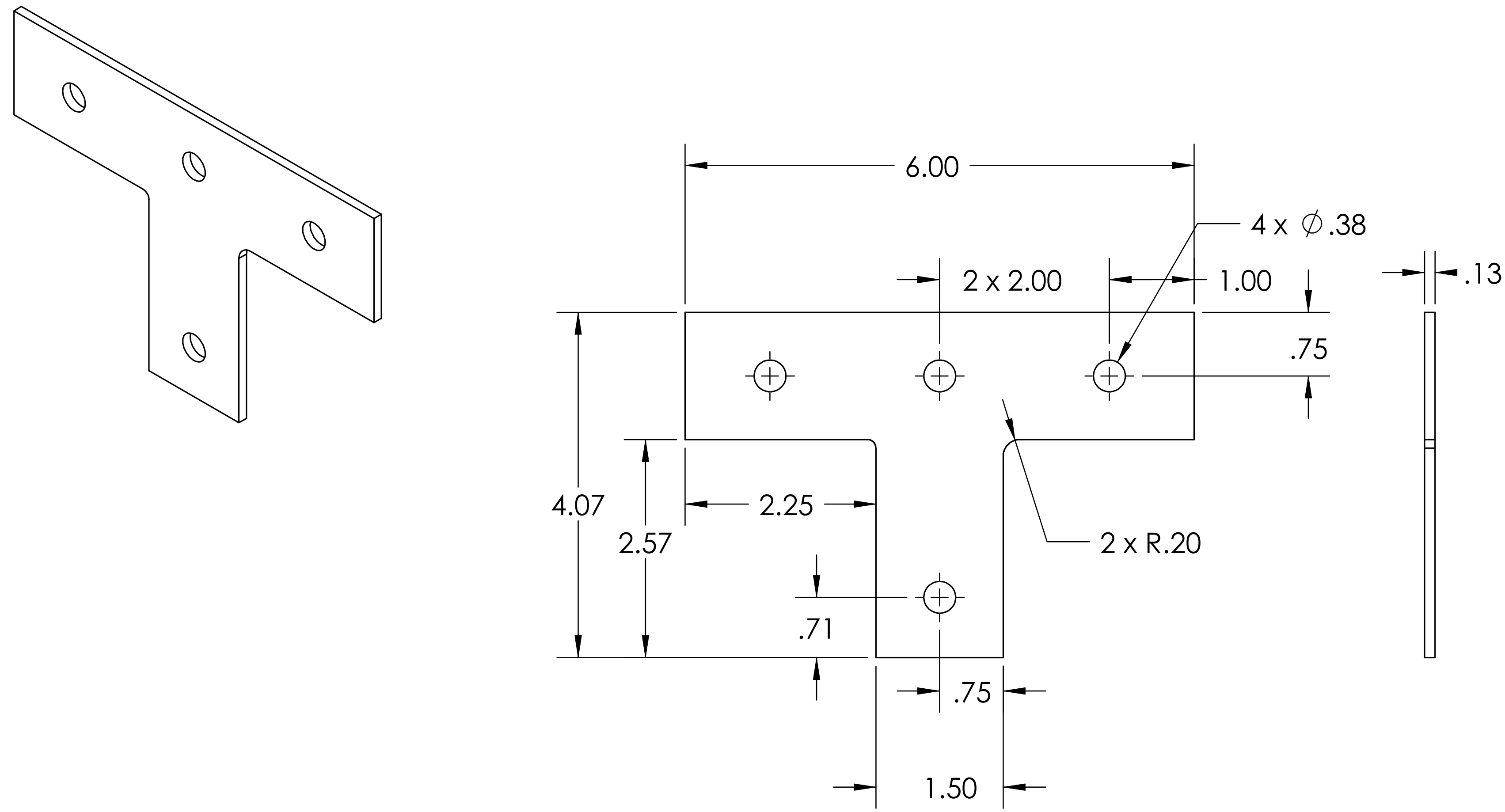
COMMENTS:

TITLE:

Upper Reservoir

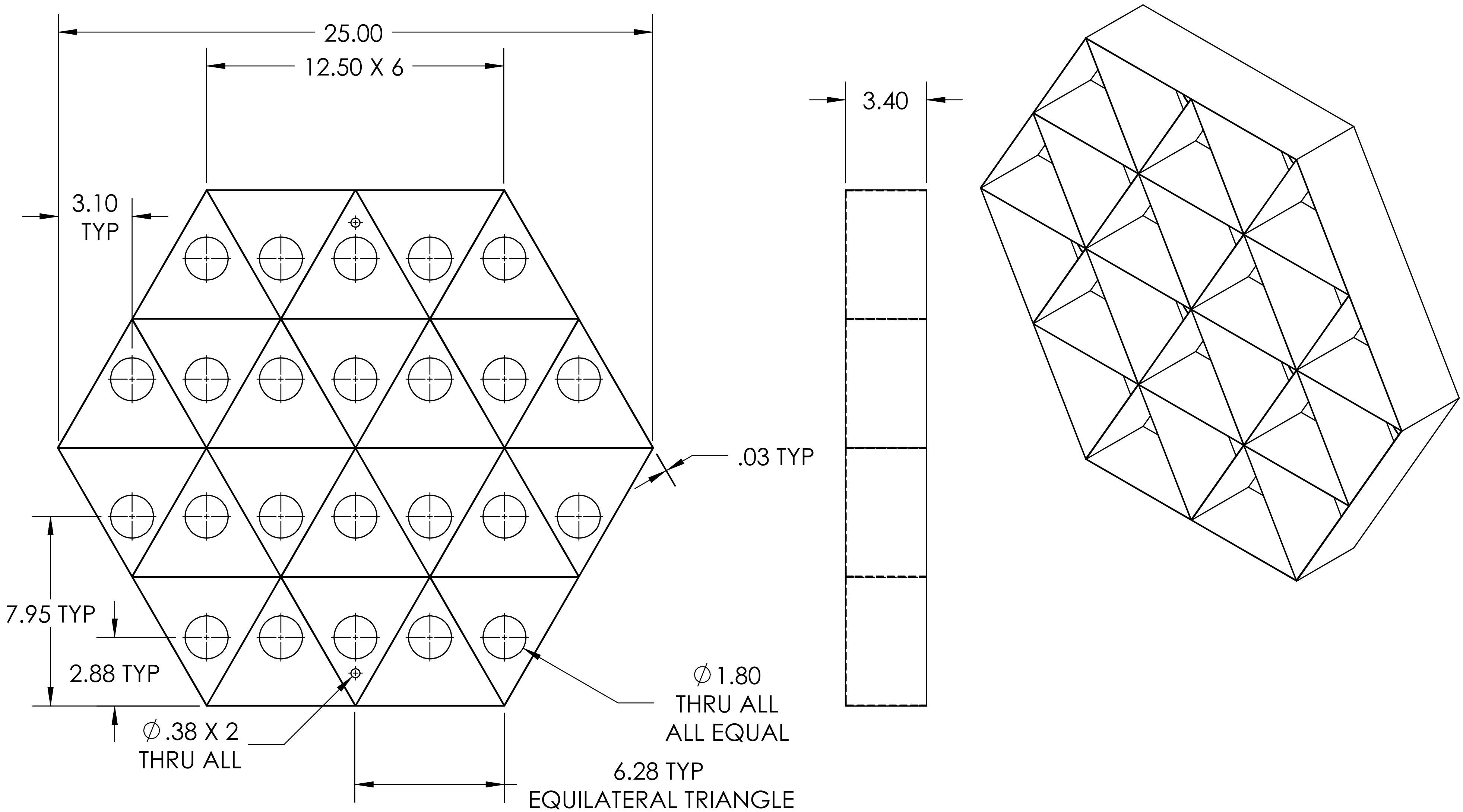
SIZE	DWG. NO.	REV
B		1

SCALE: 1:12 WEIGHT: SHEET 1 OF 1



		UNLESS OTHERWISE SPECIFIED:		NAME	DATE	
		DIMENSIONS ARE IN INCHES TOLERANCES: FRACTIONAL±1/16 TWO PLACE DECIMAL ±0.010 THREE PLACE DECIMAL ±0.005	DRAWN	Wen Li	Jan 29	
			CHECKED			TITLE: T-brackets
			ENG APPR.			
			MFG APPR.			
		INTERPRET GEOMETRIC TOLERANCING PER:	Q.A.			
		MATERIAL	COMMENTS:			SIZE A DWG. NO. REV 1
NEXT ASSY	USED ON	FINISH				
APPLICATION		DO NOT SCALE DRAWING				SCALE: 1:2 WEIGHT: SHEET 1 OF 1

5 4 3 2 1



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NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED:

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: ± 1/16
TWO PLACE DECIMAL ±0.010
THREE PLACE DECIMAL ±0.005

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL Stainless Steel

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Wen Li	09/04/10
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:

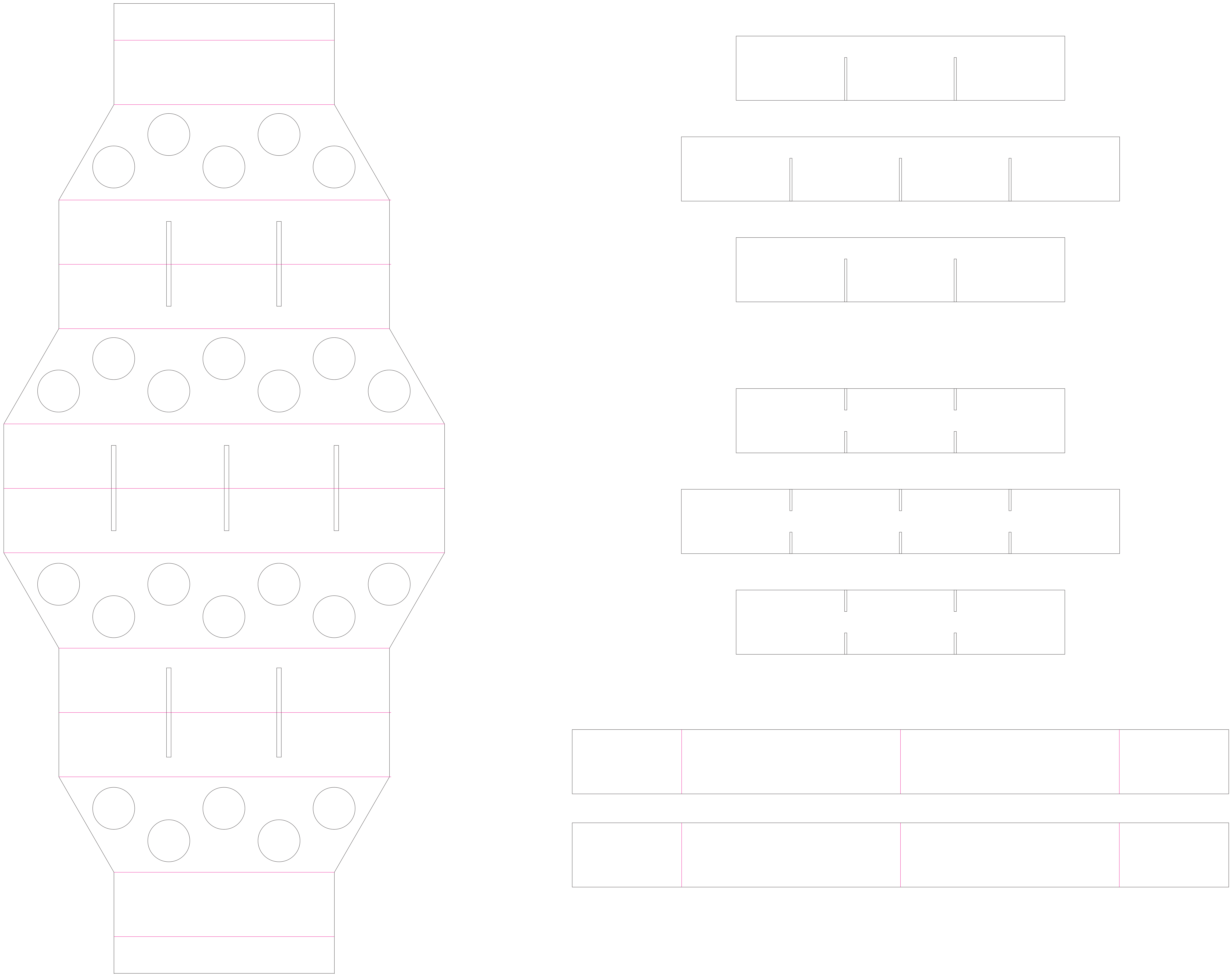
Living Wall Cell Unit

SIZE	DWG. NO.	REV
B		5

SCALE: 1:6	WEIGHT:	SHEET 1 OF 1

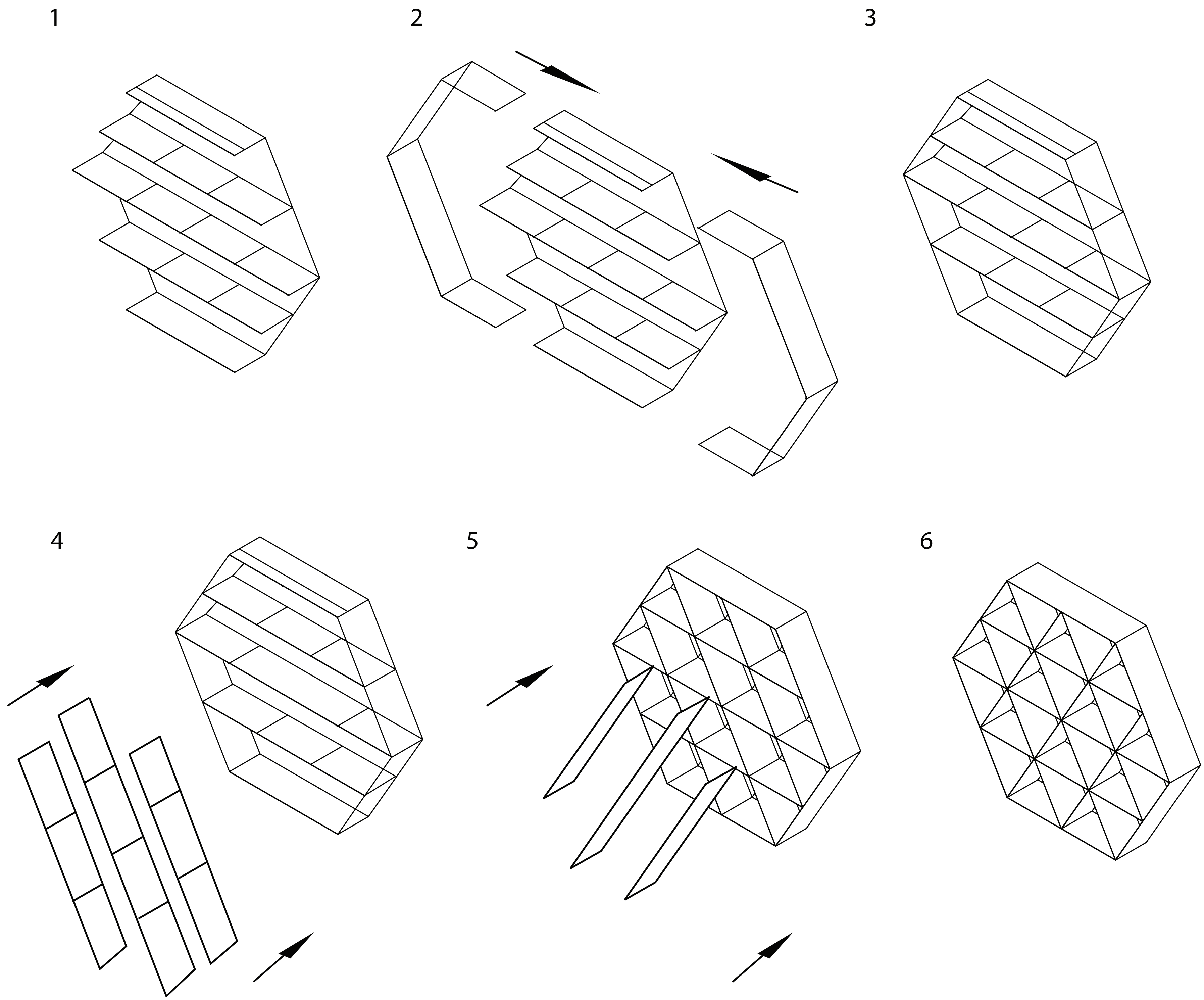
5 4 3 2 1

Appendix C Cell Manufacture



30 GA , Stainless Steel Sheet Metal

Appendix D FMEA


1
2
3
4
5
6

Classification	Function	Failure mode	Effects	S (severity	Cause(s)	O (occurrence rating)	Current controls	D (detection rating)	RPN (risk priority #)
A.1	Irrigation	Recycling pump doesn't pump water	Capilary Mat dries out	9	Mechanical failure of pump, pump gets clogged, power is out	6	Install back-up sensor and pump. Monthly inspection of all mechanical components	2	108
A.2	Irrigation	Source valve gets stuck on	Water spills over bottom tank onto floor	4	Mechanical failure of valve	7	Install overflow connected to drain	2	56
A.3	Irrigation	Top tank float switch doesn't turn pump on	Capilary Mat dries out	9	Float switch is stuck or has been disconnected or power is out	7	Install back-up sensor and pump. Monthly inspection of all mechanical components	2	126
A.4	Irrigation	Top tank float switch doesn't turn pump off	Pump stays on and water spills over top tank	7	Float switch is stuck	4	Install overflow connected to bottom tank	2	56
A.5	Irrigation	Bottom tank float switch doesn’t open source valve	Eventually water is too low for pump to work	5	Float switch is stuck or has been disconnected or power is out	7	Install low water level alarm	3	105
A.6	Irrigation	Bottom tank float switch doesn’t close source valve	Water spills over bottom tank onto floor	4	Float switch is stuck	4	Install overflow connected to drain	2	32
A.7	Irrigation	Felt rips or is not properly attached to a cell	Vegetation will dry and eventually die	6	Improper assembly, interference with felt from a bystander	1	Monthly physcial inspection of felt	4	24
B.1	Structure	Living wall skeleton structure to structural wall connections break	Living wall breaks and falls onto the atrium floor	9	Extra loading on living wall, improper assembly	1	Daily physical inspections	8	72
B.2	Structure	Structural Beam (vertical or horizontal) collapses	Some or all of the cells break off the skeleton.	8	Extra loading on a specific beam	1	Daily physical inspections	8	64
B.3	Structure	Bolt connecting cell to skeleton structure comes loose	Cell falls off wall onto atrium floor, possibly killing vegetation	7	Improper assembly, extra loading on cell	1	Daily physical inspections	7	49
B.4	Structure	Structural Beam (vertical or horizontal) rust	Beam could break off, bringing down with it a cell[s] destroying the vegetation within the cell[s]	7	Water on a structural beam over a long period of time	2	Periodic inspection of structural beams for rust.	3	42
B.5	Structure	Rotational pin for a cell[s] breaks	Cell has the possibility of rotating around its center.	2	Extra loading on cell, interference from a bystander	1	Daily physical inspections	7	14
C.1	Vegetation	Garden soxx is not in the correct position to touch the felt	The vegetation does not soak up water and eventually dries out and dies.	6	Improper assembly, interference from a bystander	1	Daily physical inspections	6	36
C.2	Vegetation	Garden soxx falls out of cell	Garden soxx and vegetation falls to the atrium floor.	6	Improper attachment, interference from a bystander	1	Daily physical inspections	3	18
C.3	Vegetation	Plant falls out of garden soxx	Plant falls to the atrium floor and dies	6	Plant grows to large, interference from a bystander	1	Daily physical inspections	3	18

Appendix E Evapotranspiration Calculations

Based on the amount of water lost between t0 and t1, an average loss of water can be calculated, based on the size of the prototype.

$$\left.\begin{array}{lll} t = 0 & \dfrac{X}{600 + X} = 0.45 & \rightarrow X = 490.9 \text{ g} \\ t = 1 \text{ Day} & \dfrac{X}{600 + X} = (0.45 - 0.0672) & \rightarrow X = 372 \text{ g} \end{array}\right\} 490.9 - 372 = 119 \text{ g}$$

$$119 \text{ g} \cdot 24 \text{ plants} = 2.85 \text{ kg} \cdot \frac{1 \text{ L}}{1 \text{ kg}} = 2.85 \text{ L}$$

$$\frac{1.6 \text{ L/day}}{24 \text{ Plants}} = 66 \text{ mL/day/Plant}$$

Appendix F Energy Calculations

To increase the sustainability of the Living Wall, excess water is recycled to be used again to water the plants. A wall of roughly 60’ height and 15’ width will require approximately 0.497kW-h per day, or $18.14 per year based on $0.10 per kW-h. A 45’ by 30’ wall will require approximately 0.382 kW-h per day, or $13.94 per year. These numbers were approximated as follows.

Known values from measurements (for a 2 foot width wall; height does not factor in)

Cycle time (time between trough refills): 1 hour, 15 minutes (1.25 hours)

Cycles per day: 24 hours/day / 1.25 cycles/hour = 19.2 cycles/day

Volume of water per refill: 1.85 gallons (7 litres)

For a 45’ height by 30’ width living wall:

Water volume per refill: 1.85 gallons * (30 feet/2 feet) = 27.75 gallons (105 litres)

Pump: Centrifugal pump from McMaster-Carr – P/N 4320K47 (1 ¼” discharge, 1 ½ HP (1.12 kW))

Approximate head rise required: 45 feet of height + 5 feet from losses through piping and fittings = 50 feet (see Table 7 below for information regarding head losses through PVC piping)

Approximate flow rate @ 50 feet: 26gpm

Refill time: 27.75 gallons/26gpm = 1.067 minutes = 64 seconds

Approximate energy consumed per refill/cycle: 64 seconds * 1.12 kW = 71.68kJ = 0.0199 kW-h per cycle

Approximate energy consumed per day:

0.0199 kW-h/cycle * 19.2 cycles/day = 0.382 kW-h/day = 139.43 kW-h/year

Operating cost @ $0.10/kW-h: ***$0.04 per day or $13.94 per year***

For a 60’ height by 15’ width living wall:

Water volume per refill: 1.85 gallons * (15 feet/2 feet) = 13.875 gallons (52.5 litres)

Pump: Centrifugal pump from McMaster-Carr – P/N 4320K47 (1 ¼” discharge, 1 ½ HP (1.12 kW))

Approximate head rise required: 60 feet of height + 3 feet from losses through piping and fittings = 63 feet (see for information regarding head losses through PVC piping)

Approximate flow rate @ 63 feet: 10gpm

Refill time: 13.875 gallons /10gpm = 0.13875 minutes = 83 seconds

Approximate energy consumed per refill/cycle: 83 seconds * 1.12 kW = 92.96 kJ = 0.0259 kW-h per cycle

Approximate energy consumed per day:

0.0259 kW-h/cycle * 19.2 cycles/day = 0.497 kW-h/day = 181.41 kW-h/year

Operating Cost @ $0.10/kW-h: ***$0.05 per day or $18.14 per year***

Note: The cycle time is simply a representation of the flow rate through the capillary mat. If the refill volume is changed, so will the cycle time. Through previous experiments, it has been shown that only the width of the wall or capillary mat will affect the overall flow rate. Per unit length, however, it is always going to be constant.

Flow Rate, gpm	Pipe Size						
	1/2"	3/4"	1"	1 1/4"	1 1/2"	2"	3"
5	23.44	5.73	1.72	0.44	0.22	0.07	0.02
10	82.02	20.04	6.02	1.55	0.72	0.21	0.03
15	___	42.46	12.77	3.28	1.53	0.45	0.07
20	___	72.34	21.75	5.59	2.61	0.76	0.11
25	___	___	32.88	8.45	3.95	1.15	0.17
50	___	___	___	30.51	14.25	4.16	0.6

Table 7- Head Losses through 100ft of PVC Piping[3]

[3] Head Losses through 100 ft of PVC Piping. Retrieved April 1, 2010, from McMaster-Carr under "About Pump Performance".

Appendix G Detailed Estimation of Construction Costs

To predict the cost of the Living Wall, prices are presented as variable and summarized for two sizes of wall; 60’ by 15’ and 45’ by 30’. Unit cost estimates take bulk prices into account where applicable. Note that these components and corresponding prices are approximate to suggest likely costs and may not be in full compliance to technical drawings. The construction cost for a 60’ by 15’ wall is approximately $67,365.26; the approximate cost for a 45’ by 30’ wall is $109,470.62.

Operation costs are presented as an annual average, based on the operations and maintenance plan suggested in Appendix H – ‘Suggested Operation & Maintenance Procedures’. The average annual cost for a 60’ by 15’ wall is estimated at $2595.82; for a 45’ by 30’ wall it is estimated at $8123.62.

*The following material and pricing specifications intend to provide approximate range of total cost in various modular setting. The materials, dimensions, pricing information and suppliers listed below are subject to change and may not be in full compliance to the technical drawings.

Initial Construction Cost

PR = Possible replacement for a similar component, ND = Not on drawing, NR = Not necessarily required, NP = Not priced due to lack of information or large variation in prices

No	Items	Unit Price	Unit Quantity	60' x 15'		45' by 30'		Source	Contact
				Quantity Needed	**Total Cost**	**Quantity Needed**	**Total Cost**		
Structure									
1	Vertical Column (304 Stainless Steel 2"X4"X6')	$296.67	0.1 (ft^2)	90	$26,700.30	135	$40,050.45	McMaster Carr	http://www.mcmaster.com/
2	Corner Brackets (Galvanized Steel 3-5/8" X 2")	$ 2.74 (50 +)	0.41 (ft^2)	369	$1,011.06	554	$1,517.96	McMaster Carr	http://www.mcmaster.com/
3	Horizontal Column (Aluminum 6063 1.5"X2"X36")	$16.64	3.3 (horizontal ft)	50	$832.00	100	$1,664.00	McMaster Carr	http://www.mcmaster.com/
4	Anchor Brackets (Aluminum 6061 U-Chanels 36"X 5"X 2.05")	$50.08	0.025 (ft^2)	23	$1,151.84	35	$1,752.80	McMaster Carr	http://www.mcmaster.com/
5	Anchor Bolt (Zinc Plated Steel 3/4" OD X 6" L	$6.98	0.15 (ft^2)	135	$942.30	203	$1,416.94	McMaster Carr	http://www.mcmaster.com/
6	Bottom Column (304 Stainless Steel 2"X4"X12")	$47.40	0.075 (ft^2)	67.5	$3,199.50	102	$4,834.80	McMaster Carr	http://www.mcmaster.com/
7, 11	Top & Bottom Water Trough (Recycled Wood 36"X 10" X 8")	$46.50	0.67 (horizontal ft)	10	$465.00	20	$930.00	Dear Green Place	Dalcross Street, Partick Glasgow G11 5RE Tel & Fax: 0141 237 8546
8	Capillary Mat (felt width = 4')	$0.40	per ft^2	900 (ft^2)	$360.00	1350 (ft^2)	$540.00	JVK Capillary Bench Matting	1 (800) 665-1642
9	Plastic Laminar (Plexiglass 8'X 48" X 1/8")	$6.25	per ft^2	900 (ft^2)	$5,625.00	1350 (ft^2)	$8,437.50	McMaster Carr	http://www.mcmaster.com/
10	Connecting Brackets (8" X 1 1/4")	$1.15 (50+)	0.075 (ft^2)	68	$78.20	102	$117.30	McMaster Carr	http://www.mcmaster.com/
12	T Bracket (5" side, 1" width)	$0.53 (50+)	0.15 (ft^2)	135	$71.55	203	$107.59	McMaster Carr	http://www.mcmaster.com/
13	Wall Anchor Washer(316 Stainless Steel 1/4"ID X 0.05" thickness)	$0.33	0.15 (ft^2)	135	$44.55	203	$66.99	McMaster Carr	http://www.mcmaster.com/
14	3/8"-16 Hex Bolt (18-8 Stainless Steel 5" in length)	$1.92	0.90 (ft^2)	810	$1,555.20	1215	$2,332.80	McMaster Carre	http://www.mcmaster.com/
15	3/8"-16 Hex Nut (18-8 Stainless Steel)	$0.09	2 per ft^2	1800	$161.46	2700	$242.19	McMaster Carr	http://www.mcmaster.com/
16	3/8" Bracket Washer (18-8 Stainless Steel 0.05" thickness)	$0.12	0.40 (ft^2)	360	$43.92	540	$65.88	McMaster Carr	http://www.mcmaster.com/
17	3/8"-16 Hex Bolt (18-8 Stainless Steel 2" in length)	$0.72	0.40 (ft^2)	360	$257.76	540	$386.64	McMaster Carr	http://www.mcmaster.com/
PR	3/6 -16 Hex Bolt (18-8 Stainless Steel 3" in length)	$0.94	0.705 per ft^2	635	$596.90	930	$874.20	McMaster Carr	http://www.mcmaster.com/
ND	Stainless Steel Sheet Metal (304 Stainless Steel 100"X12"X0.012")	$6.82 (ft^2)	9.7 (ft^2 per cell)	2445 (ft^2)	$16,674.90	3668 (ft^2)	$25,015.76	McMaster Carr	http://www.mcmaster.com/
ND	316 Stainless Steel Rivet (1/8" OD x 0.236" in Length)	$1	6 per cell	1500	$1500.00	2250	$2250.00	McMaster Carr	http://www.mcmaster.com/
Irrigation									
ND	PVC Piping (Unthreaded 1.5" ID X 8' in length)	$6.84	per vertical ft	60	$410.40	45	$307.80	McMaster Carr	http://www.mcmaster.com/
ND	Extended Life Type 316 SS Centrifugal Pump 1-1/2hp	$737.84	1 for wall	1	$737.84	1	$737.84	McMaster Carr	http://www.mcmaster.com/
ND	1 1/2" Polypropylene Sediment Removing Filter (# 44075K16)	$85.91	1	1	$85.91	1	$85.91	McMaster Carr	http://www.mcmaster.com/
ND	1 1/2" Activated Carbon Filter (#44075K28)	$118.47	1	1	$118.47	1	$118.47	McMaster Carr	http://www.mcmaster.com/

Vegetation									
ND	Bulk Soil	$2.7 (ft^3)	0.22 (ft^3 per cell)	56 (ft^3)	$151.20	84 (ft^3)	$226.80	West Creek Farms Ltd	25044 88 Avenue Langley, BC (604) 888-3426
ND	Perlite	$6	4 cells per bag	63	$378.00	94	$564	Home Depot	900 Terminal Avenue Vancouver, BC V6A 4G4 604-608-1423
ND	Activated Carbon (200 mL)	$15.00	6 cells per bottle	42	$630.00	630	$9450.00	Fraser Aquarium	4364 Fraser St Vancouver, BC V5V 2G3 Tel: 604-879-1112
ND	All-Purpose Slow Releasing Fertilizer	$12	8 cells per can	32	$382	48	$576	Park Seeds	www.parkseeds.com
ND	Plant Soxx	$1 (ft^2)	500 ft per roll; 20% discount	6000 soxx; 4000 ft	$3200.00	9000 soxx; 6000ft	$4800.00	Filtrexx International, LLC	35481 Grafton Eastern Rd Grafton, Oh 44044 Tel: 440-926-2607
NP	Plants								
	TOTAL ESTIMATED CONSTRUCTION COST			60’ x 15’:	**$67,365.26**	45’ by 30’:	**$109,470.62**		

Average Annual Operation Cost

	Items	Unit Price	Unit Qty	60’ x 15’		45’ by 30’		Source	Contact
				Quantity Required per Biennial	**Total Biennial Cost**	**Quantity Required per Biennial**	**Total Biennial Cost**		
	Plant Soxx	$1 (ft^2)	500 ft per roll; 20% discount	6000 soxx; 4000 ft	$3200.00	9000 soxx; 6000 ft	$4800.00	Filtrexx International, LLC	35481 Grafton Eastern Rd, Grafton, Oh 44044 / Tel: 440-926-2607
	Bulk Soil	$2.7 (ft^3)	0.22 (ft^3 per cell)	56 (ft^3)	$151.20	84 (ft^3)	$226.80	West Creek Farms Ltd	25044 88 Avenue, Langley, BC (604) 888-3426
	Perlite	$6	4 cells per bag	63	$378.00	94	$564	Home Depot	900 Terminal Avenue Vancouver, BC V6A 4G4 604-608-1423
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	All-Purpose Slow Releasing Fertilizer	$12	8 cells per can	32	$382	48	$576	Park Seeds	www.parkseeds.com
	Capillary Mat (felt width = 4')	$0.40	per ft^2	900 (ft^2)	$360.00	1350 (ft^2)	$540.00	JVK Capillary Bench Matting	1 (800) 665-1642
	1 ½” Polypropylene Sediment Removing Filter – Replacement Cartridge (#44075K19)	$23.89	1		$23.89		$23.89	McMaster Carr	http://www.mcmaster.com/
	1 ½” Activated Carbon Filter – Replacement Cartridge (#44075K29)	$66.54	1		$66.54		$66.54	McMaster Carr	http://www.mcmaster.com/

	Total Biennial Cost				$5191.63		$16247.23		
	AVERAGE ANNUAL OPERATION COST			60’ x 15’:	**$2595.82**	45’ x 30’:	**$8123.62**		

Appendix H   Suggested Operation & Maintenance Procedures

Start-up procedures to initialize the cells and plants are as follows. Cells should initially be stored horizontally. Seedlings should be installed in the cell and allowed to grow until stable, before cell is installed on the living wall.

1. Pre-grow 24 small seedlings per cell.

Figure 16 - Pregrown Seedling

2. Fabricate twenty-four soxx per cell at 8” length each.
3. Bind one end of each soxx by thread or tie.
4. Create small hole in the center of the soxx to allow the insertion of the seedling from the inside. Insert the plant through the hole, from the inside.

Figure 17 - Soxx Bound with Hole

5. Fill each soxx with approximately 0.6kg of soil mixture, and approximately 1 tablespoon of active carbon pellets. Soil mixture should consist of 2/3 indoor potting soil, and 1/3 perlite. Perlite is included in the mixture to provide aeration. Active carbon is included to resist the growth of bacteria.

Figure 18 - Soxx With Soil Mixture

6. Insert a slow-releasing nutrient tablet into the soil.
7. Bind the remaining end of the soxx.

Figure 19 - Filled Soxx

8. Insert the soxx into a triangular cell sub-division, ensuring that the soxx reaches back of cell.

Figure 20 - Soxx & Plants in Cell

9. Repeat for remaining sub-divisions to fill cells as necessary.
10. Water and maintain plants as necessary until cell is installed.

Condition-Based Maintenance takes place when necessary according to monthly PM inspections. This includes pumps, piping, structural components, plants, and any components not replaced at the two year interval as discussed below. All Preventative Maintenance (PM) is to be conducted at regular intervals following the start-up procedures.

1. Inspection (Monthly Interval)
   Procedure: The following items should be visually inspected:
   1. Irrigation components including water troughs, piping, and valves. Check for leaks or obvious obstructions
   2. Structural components including wall anchors, columnar support beams, and horizontal support beams for excessive rust, wear, or tampering.
   3. Vegetation for dry soil, tampering, or excessive wilting or discoloration.
2. Water Disinfection
   Procedure:
   1. Monitor, disinfect, and flush irrigation system as required according to Section 5.3.3 Inspecting the HVAC System, Indoor Air Quality from Health Canada.
3. Replacement of Main Components (felt, soil, plants) (2 Year Interval[4])
   Procedure:
   1. Prior to replacement, plant and grow replacement plants for the Living Wall. Grow in new soxx and include required slow releasing fertilizer and active carbon as in start-up procedures.
   2. Remove a single column of cells, beginning with the top most cell to ensure safety.
   3. Remove the felt lining the column against the backboard.
   4. Remove and replace soxx in each cell.
   5. Replace columnar felt lining.

[4] A. Marks, personal communication, April 2010. Filtrexx International (2009). www.filtrexx.com

6. Refasten cells to wall.
7. Repeat for all columns of the Living Wall.

Appendix I Project Proposal Report

New SUB Living Wall Project

Project Proposal

Prepared by:

Jordan Cowan
Brittany Hilbrecht
Wen Li
Jacky Ling
Wilson Tran
Stephanie Wilson

MECH 457 Capstone Design Course 2009-2010

Purpose of Proposal

This proposal is written in response to a request by the Alma Matter Society (AMS) New Student Union Building (SUB) Committee for the design of a 'Living Wall.' This proposal is prepared in partial fulfillment of these requirements. To achieve goals and meet objectives, the design team requests that the client provide a vegetation advisor and a conceptual artist/architect, as well as all available plans and information regarding the new SUB building in which the wall will be located.

Abstract

As sustainability becomes increasingly important, UBC is self-mandated to promote and encourage sustainability. In keeping with this duty and to meet the expectations of the UBC community, the design of the new Student Union Building will consider the installation of a living wall. The design of this living wall will include all sub-systems required to support and maintain the wall. The parameters of the wall and its systems will be evaluated for functionality, efficiency, and sustainability. The project will be completed over a period of eight months by a team of five students; final deliverables include a functional modular prototype and comprehensive design analysis report. In addition to improving the sustainability profile of the Student Union Building, the wall will serve as an educational tool to remind the community of the importance of sustainability.

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List of Figures

1.0 Introduction

As a leading university, UBC has a mandate to 'promote the values of a civil and sustainable society'[1]. The fulfillment of this mandate requires that sustainability be a key component in campus projects. One such project is the construction of a new Student Union Building (SUB). With the decision to construct the new building, the Alma Matter Society (AMS) SUB committee completed extensive research into the expectations and desires of stakeholders (such as faculty, staff, and students). An important factor was found to be the development of a greener campus. To fulfill UBC's mandate of sustainability and to meet the expectations of community members, the SUB committee has requested the design of this 'Living Wall' within the atrium of the new SUB building. This wall will provide a visible reminder to both the internal and surrounding communities of UBC of the importance of sustainability. This project will contribute to UBC's ability to promote the campus, increase sustainability ratings, and improve annual reports on UBC's initiatives and sustainability.

The design of the new SUB is underway, but has not been finalized. The final size and shape of the atrium are unknown, but the height of the room has been fixed at 61'. The Living Wall will serve as a focal point in the atrium. It is undecided whether the wall will be freestanding or partially supported by atrium structures, or how much floor area it will occupy.

A Living Wall is a vertical garden wall partially or fully covered in vegetation. These walls range from outdoor insulating walls to indoor decorative walls. Wall sizes vary from just a few square feet to over 2000 square feet. Smaller walls can be mounted in residential living spaces, while the larger walls may

[1] http://www.ubc.ca/about/accountability/

1.0 Introduction

cover an entire side of a building. Living walls may be constructed of wood, sustainable plastics, or composites, and may have structural components comprised of concrete and steel. Some walls require manual watering, while larger walls have an automatic timer-controlled irrigation system. The purpose of these walls is typically mainly aesthetic, although some are intended to encourage environmental awareness or improve air quality.

Figure 1 - ELT Living System

Smaller-scale modular walls are readily available for residential installation, such as those by Elevated Landscape Technologies Inc. (ELT) Living Systems[2]. The 'Single ELT Easy Green Living Wall Stand' provides a simple and easily installed living wall (Figure 1). The wall stand is composed of solid cedar, and bolts onto any wall or structure. Large-scale modular walls are also readily available for public and commercial spaces.

Figure 2 - IL Center Biowall

The Integrated Learning Center Biowall at Queens University provides a larger scale example of a Living Wall with additional functionality. The biowall is three stories tall and claims to break down airborne VOC (Volatile Organic Contaminants) through its air filtration system by actively drawing air through the wall (Figure 2). The wall consists of a porous material attached to and supported by a concrete wall[3]. There are opportunities to improve upon the systems of current living walls, such as reducing

[2] http://www.eltlivingwalls.com/
[3] http://livebuilding.queensu.ca/green_features/biowall

1.0 Introduction

supervision and maintenance requirements, water consumption, as well as improving the environment in which it is located. The ability to improve the environment around the wall (in terms of air quality) will not only provide a healthier environment for users, but will contribute to the sustainability profile of the building.

The Living Wall Design Team aims to design and construct a small-scale prototype, approximately 5 ft^2, of a functional living wall that supports plant life and its corresponding ecosystem as sustainably as possible. It will serve to improve the indoor environment of the atrium, in terms of air quality, insulation, and humidity. The aesthetics of the wall will be a medium for communicating an educational message to promote UBC's commitment to sustainable development.

2.0 Requirements & Evaluation Criteria

By definition, a Living Wall has vegetation. In order to physically support the vegetation, a structure is required. As the size and shape of the atrium are uncertain, the structure should be modular to allow for flexibility in the final design. In order to sustain the vegetation in an indoor environment, irrigation is needed. The irrigation system should be such that the amount of water required is minimized. While vegetation naturally reduces carbon dioxide in the air, the wall will further improve air quality by active ventilation. The wall will also include an educational component which will demonstrate the functionality and sustainability of the wall. These characteristics of the wall suggest the six main sub-functions.

2.1 Functional Requirements of Subsystems

System Structure

Function:
- Supports the system mechanically in a stable, freestanding manner

Constraints:
- Resists corrosion, moisture and oxidation
- Attracts viewers' attention with visually pleasing design
- Uses materials with minimal environmental impact
- Orientates the structure to capture sunlight
- Adapts to various atrium sizes (atrium design to be finalized in 2010)
- Provides access for maintenance purposes

Irrigation

Function:
- Distributes water to vegetation

Constraints:
- Provides an adequate amount in a controlled manner
- Collects runoff water from the system

Monitoring

Function:
- Provides information on status of the system (e.g. pH, soil moisture)
- Controls the opening/closing of valves
- Monitors water levels and flow rates
- Warns of impending failures

Ventilation

Function:
- Actively draws air from surroundings across the vegetation and soil for contaminant breakdown and air exchange

Constraints:
- Maintain sufficient volume of air flow

Vegetation

Function:
- Breaks down air contaminants and enhance aesthetic value of the wall

Constraints:
- Grows with minimum sunlight and suitable for indoor environment
- Grows at an appropriate rate
- Produces few or no hypoallergenic effects

Education

Functions:
- Conveys information on benefits of the system
- Displays monitored system status
- Explains engineering design features
- Highlights the beauty of incorporating biological features in architecture

2.2 System Constraints

System Overview

Constraints are largely dictated by industry standards. Physical atrium parameters (Table 1) are defined by the client and will impact the size and configuration of the final design.

Building Specification

Height of the Atrium	61’
Surface Area of the Atrium	1802 - 4541 ft^2

Table 1 - New SUB Building Specification

The wall will be designed to ensure that air quality standards, as specified by The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), are maintained (Table 2). Additional industry standards may also be applicable.

Air Quality Constraints

Ideal Relative Humidity [4]	Winter: 20% to 30%	Summer: 50% to 55%
Room Temperature [4]	Winter: 21 to 23 C	Summer: 23 to 26 C
Indoor Air Movement [4]	4 to 10 ACH	

Table 2 - New SUB Air Quality Constraints

[4] 2003 ASHRAE Application Handbook (SI)

2.3 Evaluation Criteria

The Living Wall will be evaluated according to a set of pre-determined performance indices, as follows:

1. **Structure** — *Safety Factor: 1.5*
   The support structure must meet a minimum safety factor of 1.5 for strength in supporting the static load from the vegetation, irrigation, ventilation, and monitoring systems. This safety factor complies with industry standards for static structures in which there is no shock or cyclic loading [5].

2. **Irrigation** — *Maintain 25-35% water content by volume*
   In order to keep the supported plant life healthy, the irrigation system needs to be capable of keeping the water content within each cell between 25-35% by volume [6].

3. **Monitoring & Control** — *Maximize Benefits of Number of Sensors vs Cost*
   The monitoring system must control the water content of the soil and provide feedback to the irrigation system, using equal to or less than one sensor per area of one foot squared [7].

4. **Ventilation** — *Flowrate to be determined*
   Further prototype testing for the irrigation must first be done before the ventilation system can be evaluated. Testing will be carried out to determine what size and horsepower of fan is required to provide a sufficient volume of air flow.

[5] Shigley, Chapter 1, 2008
[6] http://en.wikipedia.org/w/index.php?title=Water_content&oldid=334060648, November 5, 2009
[7] Vernier, Soil Moisture Sensor Manual, 2009

2.3 Evaluation Criteria

5 **Vegetation** — *Various Criteria*

The vegetation chosen for the wall must:

- i Grow at a limited and manageable rate
- ii Require basic maintenance cycles of at least 2 weeks or (preferably) longer
- iii Not be a source of common allergens
- iv Not attract too many pests
- v Comprise of plants species with a range of different shades and colors for aesthetic appeal

6 **Education**

Education serves to educate the public regarding how the living wall works, what benefits it provides, and why the sustainability of the wall is important. This educational component of the wall will include visual and possibly interactive explanation. Informal surveys and interviews may be conducted among students to determine what can be done to improve upon the system.

3.0 The Work Plan

The project major milestones are based on submission dates required by MECH457 and are listed in Table 3. Performing each individual and team task will ensure we stay on track to finish the project by the end of the second semester. The final deliverables for the living wall project are a final report outlining the complete design process, and a working prototype; a Gantt chart has been created to assist the team in scheduling important tasks and deadlines, and can be seen in Appendix A - Gantt Chart.

Milestones & Related tasks	Submission Date
Project Selection	**13 SEP 2009**
Conduct Initial Research Write Project Proposal **Project Proposal**	**5 OCT 2009**
Research Existing Living Walls and Patents Write Reference Report **Reference Material Report**	**19 OCT 2009**
Generate Concepts for Subsystems Winnow and Evaluate Concepts Write Concept Alternative Report Prepare for Concept Presentation **Concept Alternative Presentation/Report**	**3 NOV/ 9 NOV 2009**
Determine Prototype Critical Subsystem Test Prototype Write Critical Function Report **Critical Function Report**	**30 NOV 2009**
Perform Calculations for Each Subsystem Find Critical Design Criteria for Each Subsystem Write Technical Analysis Report **Technical Analysis Report**	**25 JAN 2010**
Construct Remaining Subfunctions Prepare Presentation **Prototype Build Presentation**	**6 MAR 2010**
Write Final Report and Prepare for Celebration **Final Report**	**19 APR 2010**

Table 3 - New SUB Living Wall Project Tasks

4.0 Roles of Team Members

The design team consists of five fourth-year UBC Mechanical Engineering students and one fourth-year Emily Carr Industrial Design student. Each member of the team has been assigned a role based on previous experience and personal strengths.

Brittany Hilbrecht — Coordinator

The coordinator is responsible for creating the overall project timeline and scheduling of meetings. To ensure the team meets all deadlines, the coordinator will also keep weekly progress reports.

Brittany's strengths include planning and coordinating events and schedules. She assisted in the scheduling for design/production of animal trials in her past employment, and she has been a coordinator at UBC Okanagan where she co-founded the first heavy lift team. She enjoys being a leader and motivating team members to get their appointed tasks completed on time.

Jordan Cowan — Liaison

The liaison keeps an open line of communication between the team, internal UBC experts, external industry professionals, and the client. He will ensure the client's needs and concerns are properly addressed.

With work experience in irrigation, landscaping and architecture, Jordan remains in contact with many industry professionals. Jordan also spent two summers managing a small house painting business, where he worked directly with clients on a daily basis.

Stephanie Wilson — Editor

All technical papers will be a combined effort from the team. The editor will make sure these documents are properly formatted, written with consistence, and presented professionally.

Stephanie has strong writing, spelling, and grammar skills. She has experience producing professional reports for several previous employers.

4.0 Roles of Team Members

Jacky Ling — Director of Design

The director of design is responsible for formatting the published documents and presentations appropriately for clear and easy reading. Jacky will ensure published documents and presentations are designed to a consistent and functional aesthetic.

Jacky Ling is a 4th-year Emily Carr University Industrial Design student with an interdisciplinary background in communication and industrial design. He is a designer at The Fairchild Group, an influential Asian Media Group and Conglomerate in Canada, with a focus in business & merchandise branding. As director of design and presentation, Jacky's professional understanding in typography and design will contribute positively to the communication and presentation of the project.

Wen Li & Wilson Tran — Technical & Financial Managers

The responsibilities of the technical and financial manager are to check calculations, complete drawings and maintain the team budget. Because of the large workload associated with the position, two team members will be sharing the role.

Wen has extensive CAD knowledge from previous work experience. In addition, she has studied Computer Aided Design at BCIT, and is certificated in AutoCAD, SolidWorks, Autodesk Inventor and hand drafting. As a senior member in the UBC Supermileage Team, Wen has been involved in sponsorship and budget management.

Wilson worked as a purchaser at an industrial pumping solutions company and brings experience working with suppliers within the lower mainland. He will be helpful with sourcing components as well as negotiating reasonable pricing for parts.

5.0 Resources Required

Key to the success of the design team is its access to important resources. Personnel resources will give advice in their respective areas of expertise. Facility resources give the team all the necessary means to create a working model of the design.

Personnel

- ***Visual Renderings:*** Art Institute graduate Steffen Quong.
- ***Solid Modelling:*** UBC Mechanical Engineering student Phillip Barron; formerly of Zodiac Boats.
- ***Building Plans:*** UBC student Jensen Metchie and the SUB contracted architect.
- ***Irrigation Expertise:*** Steve Wellenbrook of Active Turf Irrigation
- ***Monitoring/Control Expertise:*** Rod Mckeown of Hoskin Scientific Distributors
- ***Ventilation Expertise:*** Dr. Nima Atabaki, department of Mechanical Engineering UBC
- ***Structure Expertise:*** Graham Smith of Smith architecture
- ***Vegetation Expertise:*** Dr. Andrew Riseman of the UBC Botanical Garden and Centre for Plant Research
- ***Consulting:*** The project will be guided by UBC advisor Paul Winkelman. Further consultation is provided by clients SUB renewal liaison Jensen Metchie and SEEDS Program Sustainability Coordinator Liska Richer.

Facilities

- ***Computer Simulation:*** The PACE lab and CEME Lab offer important modeling and design software like AutoCAD and Unigraphics.
- ***Prototyping:*** The UBC machine shop allows the team to create custom parts in-house. Further testing and construction will be done in the Rusty Hut 118 Laboratory, located on the UBC campus.

Budget

The majority of the budget for this project will be the $750 allocated by the UBC department of Mechanical Engineering for the course project. Further funding may be available through sustainability funding; this amount has yet to be determined.

6.0 References and Appendices

References

[1] http://www.ubc.ca/about/accountability/
[2] http://www.eltlivingwalls.com/
[3] http://livebuilding.queensu.ca/green_features/biowall
[4] 2003 ASHRAE Application Handbook (SI)
[5] Shigley, Chapter 1, 2008

[6] http://en.wikipedia.org/w/index.php?title=Water_content&oldid=334060648, November 5, 2009
[7] Vernier, Soil Moisture Sensor Manual, 2009

Appendix A - Gantt Chart

[Not included due to the size of the file; available in report drafts upon request – will be included in final draft]

Appendix J Reference Report

MECH 457
Reference Report

SUB Living Wall Team

Stephanie Wilson
Brittany Hilbrecht
Wen Li
Wilson Tran
Jordan Cowan
Jacky Ling

Submitted: October 19, 2009

Word Count: 2154

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List of Figures

1.0 Introduction

The concept of a vertical garden as a Living Wall is recent but not new. There are many Living Walls in existence around the world, and technologies available to support vegetation are extensive. In addition, many kits and pre-fabricated Living Wall panels are available for purchase. In the design of a Living Wall, existing products and technologies must be carefully researched to avoid infringing upon current patents, as well as to avoid wasting energy and time reinventing current technologies.

Research was successful in providing information on Living Wall systems, as well as technologies available to fulfill the main sub-functions of the wall, including structure, irrigation, monitoring, and ventilation. The interaction of users with the wall was also considered, and design decisions will be made so as to maximize positive experiences provided to users.

2.0 Existing Products

Many living walls are currently in existence around the world. They employ a variety of systems and technology to compose and sustain them. Extensive research provided much insight into existing products and technologies that could be applied to this project.

Vertical Garden by Patrick Blanc. (n.d.). Retrieved October 15, 2009, from http://www.verticalgardenpatrickblanc.com/

A look at the "Vertical Garden" (Le Mur Végétal, The Vegetal Wall) by French botanist - Patrick Blanc. The Vertical Garden relies on a system allowing plants to grow on a wall without any soil.

BioWall. (2006). *Queen's University Faculty of Applied Science*. Retrieved October 10, 2009, from http://livebuilding.queensu.ca/green_features/biowall.

A Living Wall system; three stories high, with an active ventilation system. Water is recycled, stored, drained, and pumped from the bottom of the wall. Wall material composed of porous plastics; wall is proven to be a natural filter of volatile organic compounds and CO_2.

Figure 1 - Queen's University Biowall retrieved from http://livebuilding.queensu.ca/green_features/biowall

Green Wall. (2009). *Queen's University Faculty of Applied Science.* Retrived October 3, 2009, from http://appsci.queensu.ca/ilc/greenBuilding/greenwall/greenwall_03.php.

A description of Living Wall systems and how they work. Explanation of a Green Wall providing relief of 'Sick Building Syndrome' and 'Urban Heat Island' effects. A green wall can be a biofilter that eliminates air contaminants via microbes in the soil, and uses an active ventilation system to provide a more effective filtering system. Diagram shown in Figure 2.

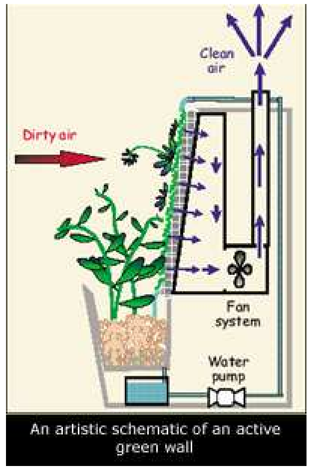

Figure 2 - Green Wall retrived from http://appsci.queensu.ca/ilc/greenBuilding/greenwall/greenwall_03.php

Modular Vertical Garden Systems. (2008). *VertiGarden*. Retrieved October 18, 2009, from http://vertigarden.com/.

Vertical garden trays that provide quick and easy installation of vertical flowers or vegetation. Provides only structure and physical support of vegetation system, does not include self-irrigation.

Living Wall Planting Ideas. (2009). *ELT Living Walls.* Retrieved October 18, 2009, from http://www.eltlivingwalls.com/planting_ideas.php.

Provision of living wall panels that are easily installed inside or outside. Kits come in various sizes with a simple irrigation system. Also includes design ideas, irrigation information, and several other living wall projects around the world.

3.0 Patterns of Use & Functionality

In this design process both the functionality of the Living Wall and its sub-systems, as well as the interactivity of its users must all be taken into consideration. There are two dominant groups of users with regards to Living Wall - private personnel, and public users.

Private personnel include support and maintenance staff operating the Living Wall and its sub-systems. The functionality and status of the Living Wall and its sub-systems will have to be made accessible and serviceable to this group for inspection and maintenance. This inspection and maintenance will include upkeep of the vegetation (such as pruning), and regular checks to ensure the monitoring and irrigation systems are functioning properly. These checks will be visual in nature and require little time or equipment.

Public users are students, staffs, and guests at the university. This group will experience the performance of the Living Wall's sustainable features, and interact with the educational aspect of the Living Wall. There are two sub-groups amongst the public users - occupants and visitors. Occupants are users who come to use the atrium and facilities of the building and the visitors are users travelling through the building to other campus locations.

To accommodate this range of user groups and their interactivity with regards to designing the Living Wall, the following must be considered: the function of the atrium (the intended purpose of this space), the function of the Living Wall (what should be communicated to the user via environmental stimuli and/or cognitive activity), volume and frequency of users (who uses the space and when) and the degree of accessibility to the Living Wall and its sub-systems for both private personnel and public users (how users will interact with the Living Wall).

4.0 Key Technologies

The Living Wall system requires several sub-systems to compose and sustain it. These include the structure, irrigation, monitoring, ventilation, vegetation, and education. The initial stages of the project require the research and design of the structure, irrigation, monitoring, and ventilation. Vegetation and educating will be considered near the end of the project, as they will depend on the four previously mentioned components. Research into current products, technology, and patents provided several viable options for these sub-systems of the Living Wall.

4.1 Structure

It is not assumed that the structure of the Living Wall will be simply a vertical wall; other shapes and formations of the wall, as well as methods of containing the vegetation, are possible. Current patents and existing Living Walls show a range of possibilities and provide inspiration for creative decisions.

Kenneth, W.D. (1994).*U.S. Patent No. 5,363,594.* Washington, DC: U.S. Patent and Trademark Office.

> US Patent 5,363,594 on Vertical Gardens patents the concept of several vertically self contained plant containers in series, as shown in the figure below. The patent shows that there are several different ways to design the structure of a vertical wall; it does not have to be a rectangular wall.

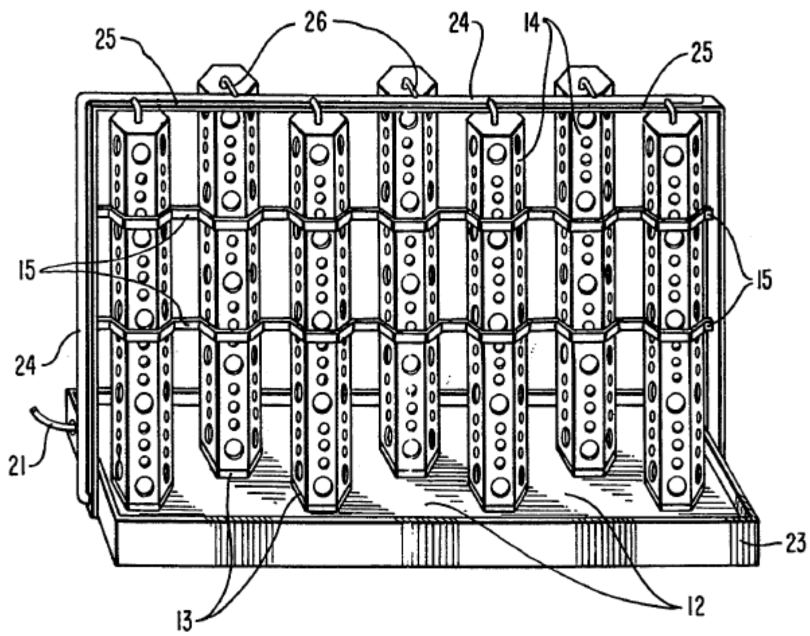

Figure 3 - Vertical Plant Containers in Series

Fukuzumi, Y. (1996).*U.S. Patent No. 5,579,603.* Washington, DC: U.S. Patent and Trademark Office.

US Patent 5,579,603 describes a way to not only grow the plants for a living wall but how to contain them. This patent uses a bag to encapsulate the soil, and plant life as shown in the figure below. Finding a way to ensure the plant does not fall off the wall is extremely important and since this patent was filed in 1996 the concept of a bag can not be used for our design.

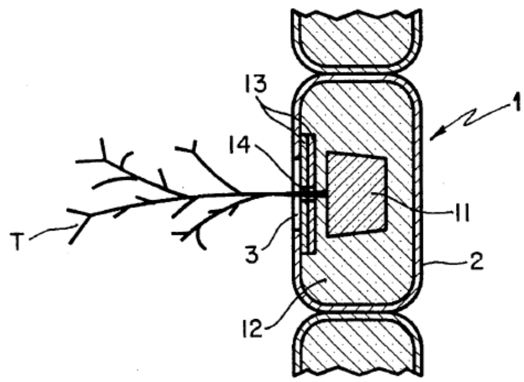

Figure 4 - Soil Bag-Style Wall Design retrieved from http://www.patentstorm.us/patents/5579603.html

Whole Foods Wall, Cambie St & West 8th Avenue, Vancouver, BC

The Living Wall at Whole Foods in Vancouver is an example of modular style of Living Wall. Individual plant boxes are hung on the wall to form a grid pattern.

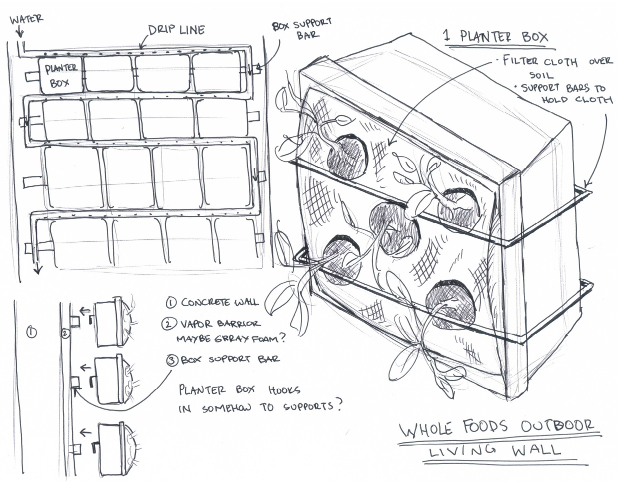

Figure 5 - Whole Foods Living Wall Sketch

4.2 Irrigation

The irrigative system of the Living Wall will be based on current irrigation technology; extensive technology is available to provide many different options for design.

Northern Garden Supply. (2004). Retrieved October 4, 2009, from http://www.northerngardensupply.ca/index.htm

Northern Garden Supply describes the process of drip irrigation and explains disadvantages and advantages. Application and key aspects of drip irrigation are discussed, and sources for further information and products is provided. The efficiency of drip irrigation is compared to overhead sprinklers.

T-Tape. (2008). Retrieved October 4, 2009, from http://www.t-tape.com/index.aspx
T-Tape designs, manufactures and sells T-Tape drip irrigation solutions. Their website includes elaborate videos on how the drip tape works and why it's beneficial to agriculture. Installation is discussed, in terms of burying the drip tape in soil and watering plants directly at the roots.

G Sky. (2008). Retrieved October 4, 2009, from http://www.g-sky.com/
G-Sky designs and produces green wall and roofs. The layout and use of valves, regulators, and filters with a drip irrigation system is discussed, and details and drawings are provided.

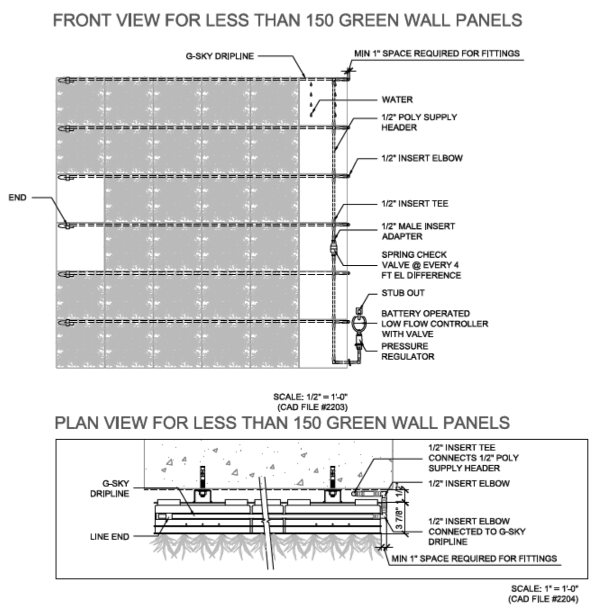

Figure 6 - Sample Irrigation Layout retrieved from http://www.g-sky.com/GreenWallPanels.aspx

DripWorks. (2009). Retrieved October 8, 2009, from http://www.dripworksusa.com/design.php.
DripWorks provides several spray irrigation options for a variety of environments and applications. Design of irrigation systems for several applications is discussed, and product options and design considerations are provided.

Figure 7 - Example of spray irrigation technology retrieved from http://www.dripworksusa.com/store/sprayer.php#MSTY

4.3 Monitoring

The Living Wall soil will have an automatic water content monitoring system. This will ensure the vegetation receives sufficient water without wasting water on a timed irrigation system. A range of acceptable moisture content will be determined based on the vegetation of the wall, and the average conditions of the wall`s environment. The monitoring system will determine the moisture content of the soil, and determine if and how much water needs to be distributed to portions of the wall. The system will be automatic to avoid supervision requirements and to decrease maintenance costs.

There are many variations of soil moisture measuring methods including sensors and probes, tensiometers, or by direct inspection. The end result of each method is to calculate the volumetric water content in the soil. This data will be recorded, stored, and reported by a data collection device.

4.3.1 Soil Water Content Information

National Sustainable Agriculture Information Service. (2009). Retrieved October 13, 2009, from http://www.attra.ncat.org/attra-pub/soil_moisture.html

> The National Sustainable Agriculture Information Service website provides a large amount of information on soils, water management, and sensors for water content. This website will be beneficial to the team as it provides a step to step process in finding the best way to monitor our plants; starting from determining the type of soil we are working with to where to place the sensors.

4.3.2 Sensors and Probes

Sensors and probes are used to measure the volumetric water content of soil by determining the dielectric constant of the soil. A high-frequency radio wave is sent out of the sensor rods through the soil and the difference is impedance is used to accurately calculate the dielectric constant of the soil.

Hoskin Scientific. (2009). Retrieved October 4, 2009, from http://ehoskin.xplorex.com/?p2=/modules/hoskin/categoryproducts. jsp&parentId=6969.

Soil moisture sensors are designed to be plugged in to the soil. The sensors collect data through extending rods, which are available 7 – 30 cm long.

Figure 8 - WET Sensor from Delta-T Devices retrieved from http://www.hoskin-environmental.ca/?p2=/modules/ hoskin/categoryproducts.jsp&parentId=6969&productId=1573

Probes are designed to be buried in the soil. These devices are more rugged than the sensors, and are made for longer and more permanent placement in the soil. However the data collecting rods are much shorter than the sensors. The ThetaProbe from Delta-T Devices is shown in Figure 9 - ThetaProbe from Delta-T Devices.

Figure 9 - ThetaProbe from Delta-T Devices retrieved from http://www.hoskin-environmental.ca/?p2=/modules hoskin/categoryproducts.jsp&parentId=6969&productId=1573 /

ESI Environmental Sensors Inc. (2009). Retrieved October 5, 2009, from http://www.esica.com.

ESI provides a variety of products from point sensors with a hand-held unit display, to an entire data acquisition system. Sensors are adaptable to a variety of soil conditions, and capable of interfacing with other irrigation controlling equipment. An example of a sensor is shown in Figure 10.

Figure 10 - Sensor from ESI Environmental Sensors Inc retrieved from http://www.esica.com.

4.3.3Tensiometers

Soil Moisture Equipment Corp (2009). Retrieved on October 6, 2009, from http://www.sowacs.com/sensors/tensiometers.html.

> Tensiometers provide a mechanical measurement of soil moisture. A tensiometer consists of a small tube that is filled with water and inserted into the ground. A self-regulating vacuum level on top of the tube increases or decreases depending on moisture content. An external gauge measures the vacuum pressure and notes changes. Figure 11 shows a tensiometer; Figure 12 explains how values are interpreted.

Figure 11 - Tensiometer from Soil Moisture Equipment Corp retrieved from http://www.sowacs.com/sensors/tensiometers.html..

Table 2. Irrigation Guidelines Based on Centibar Readings	
Reading	**Interpretation**
0-10 centibars	Saturated soil
10-20 centibars	Most soils are at field capacity
30-40 centibars	Typical range of irrigation in many coarse soils
40-60 centibars	Typical range of irrigation in many medium soils
70-90 centibars	Typical range of irrigation in heavy clay soils
> 100 centibars	Crop water stress in most soils
Adapted from Watermark Soil Moisture Sensors, The Irrometer Company, Riverside, CA.	

Figure 12 - Irrigation Guidelines for Tensiometers retrieved from http://attra.ncat.org/attra-pub/soil_moisture.html

4.4 Ventilation

The wall will include a ventilation system to ensure air flow around and through the wall. Research shows that drawing air through the wall uses the soil as a filter to remove volatile organic compounds and carbon dioxide from the air, as illustrated below in Figure 13. The use of fans to draw the air and filters to further clean the air will be considered. Many products exist that can provide these functions to any system, including the Living Wall. Several varieties of fan systems are available for different applications and situations.

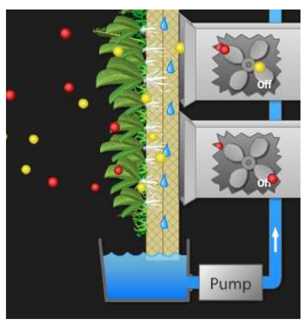

Figure 13 - Active Ventilation Filter retrieved from http://livebuilding.queensu.ca/green_features/biowall

HEPA Corporation. (2009). Retrieved October 8, 2009, from http://www.hepa.com/. A high efficiency air filter (HEPA Filter) removes at least 99.97% of airborne particles, 0.3 micrometers or larger in diameter. This filter is most commonly found in vacuum cleaners, but would provide air filtration through a living wall system as well.

Figure 14 - HEPA Filter retrieved from http://www.hepa.com/products/detail_hepa-sep.asp

Air Turbine. (2007). ATP Catalog. Retrieved from http://www.airturbine.com on October 13, 2009.

Air Turbine provides several kinds of fans for all applications. Fans can be sized according to type, diameter, depth, cubic feet per minute of air movement, or horsepower requirements.

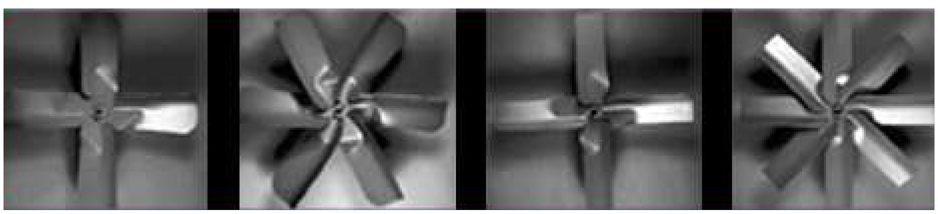

Figure 15 - Turbines retrieved from http://www.airturbine.com/catalog/catindex.html

Continental Fan. (2009). *Continental Fan E-catalog*. Retrieved from www.aeroflo.com on October 13, 2009.

Continental Fan supplies commercial, industrial, and custom fans for all applications. Fans can be selected based on dimensions, performance ratings, application environment, and maintenance requirements.

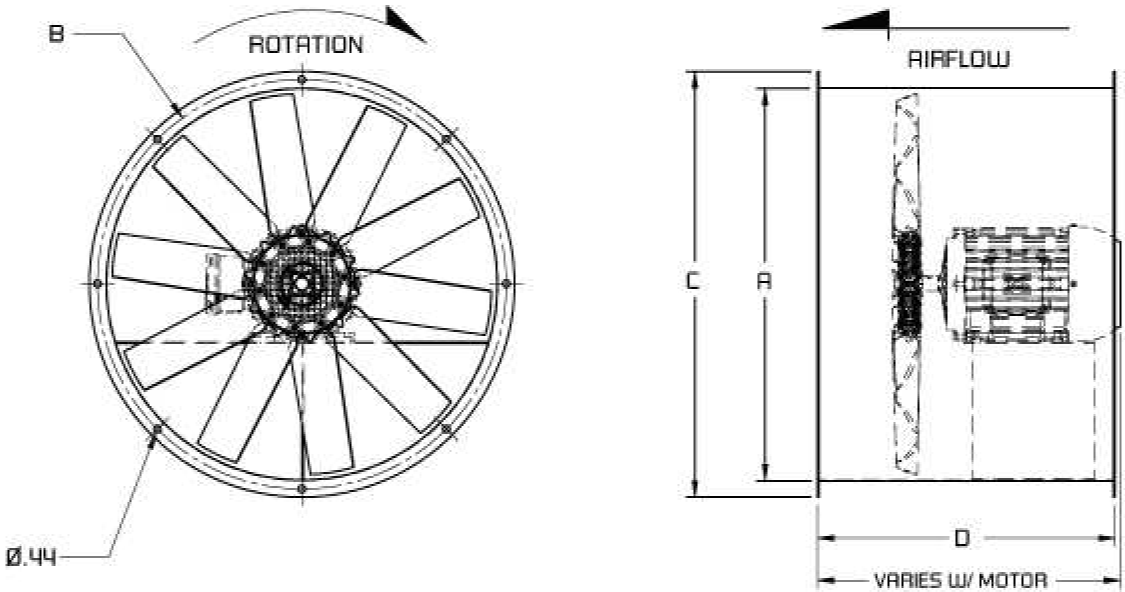

Figure 16 - Tubeaxial Fan retrieved from http://www.aeroflo.com/ecatalog.php?fantype=industrial&fid=8&s=Tubeaxial+Fan

5.0 Summary & Conclusions

Research of existing Living Wall systems and structures, and information regarding current technology for irrigation, monitoring, and ventilation methods confirmed that the sub-functions thought to be required for the Living Wall were correctly identified. The research was most beneficial in providing information on what is available through industry and suppliers to meet the requirements of the wall's sub-functions. Design efficiency will be increased by utilizing relevant technology that has already been designed and optimized for specific applications. The information gathered and presented in this report will assist in using current technologies as possible.

Many formations and shapes for a current wall are possible and can be seen in existing living walls; the wall is not necessarily required to be vertically flat and square. Agricultural industry provides many options for automatic irrigation, including drip tapes and lines, drip systems, and irrigative sprayers. Sensors, probes, and tensiometers are available to monitor the water content of the vegetation cells, and to control the irrigation system. Active ventilation will be implemented within the wall, to allow the soil to reduce harmful particles in the air. A variety of ventilation systems, filters, and fans are available to achieve this objective. The wide range of technology available for these sub-systems of the wall will aid in the design and implementation of this Living Wall.

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Whole Foods Wall, Cambie St & West 8th Avenue, Vancouver, BC

Appendix K Conceptual Alternatives Report

New SUB Living Wall Project

Conceptual Alternatives Report

MECH 457 Capstone Design

Stephanie Wilson

Jacky Ling

Wilson Tran

Wen Li

Jordan Cowan

Brittany Hilbrecht

Submitted: Monday, November 9, 2009

Purpose of Report

The purpose of this report is to discuss the concepts generated to satisfy the sub-functions required to compose a living wall. The systems required to complete these concepts, as well as the integration off various concepts is discussed. Concepts are evaluated by screening and scoring, to determine the best solution. Steps required to validate concepts are discussed.

Abstract

To increase the sustainability of the UBC campus and to promote sustainability to the surrounding community, the design of a living wall has been requested to contribute to the sustainability of the new Student Union Building. This will include the fulfillment of the main sub-functions required to construct and maintain a functional living wall. The generation of possible solutions to these sub-functions and , integration of these solutions and sub-function systems is discussed. Solutions are evaluated and recommended solutions decided upon. These potential solutions will be validated using surveys and prototypes.

In order to sufficiently address all sub-functions of the wall, and include all detail and discussion requested by the report requirements, this report exceeds the suggested word count. As this project is extensive and includes many aspects, the design team requests leeway in regards to the size of this report. As much information was moved to the appendices as possible, without significantly reducing the quality of the report.

Word Count(excluding tables & figures): 3803

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1.0 Introduction

As sustainability becomes increasingly important to society and the future, it is also increasingly important to UBC as an institution and to the UBC community. To improve the sustainability of the campus and increase awareness of the importance of sustainability, it was requested that a Living Wall be designed to be considered in the construction of the new Student Union Building. This wall will serve to increase the sustainability of the building, and to provide a visual reminder of the importance of sustainability. In order to fulfill the requirements of this design, six critical sub-functions were identified: irrigation, monitoring, ventilation, structure, vegetation, and education. These were determined based on information gathered from research on current living walls, benchmarking, and the requests of the client. Further information regarding the determination of these sub-functions, requirements, and evaluation criteria can be found in the Living Wall Project Proposal. To satisfy these sub-functions, numerous concepts were generated and considered. Concepts were evaluated individually; the integration of the concept into the system and the integration of multiple systems was considered. Finally, the method of validation of concepts to follow is summarized.

2.0 Benchmarking

By studying other functionally similar designs, the team gets valuable information on living walls that are already in use. This information can be analyzed to influence the design by building on existing designs strengths or by improving upon current designs. The ELT Easy Green Living Wall and the Vertical Garden by Patrick Blanc living walls were chosen to be reviewed as they have different methods of meeting the same overall functional requirement of supporting plant life. An indepth analysis of user interaction and an evaluation criteria comparison can be found in Appendix A – Benchmarking.

2.1 ELT Easy Green Living Wall

The ELT living wall is one of the few complete walls available for public purchase. This modular wall features angled cells which use gravity to hold soil and plants in place. The wall is designed for indoor and outdoor use and can be used for small residential applications, or large commercial projects.

Figure 1 - ELT Angled Cells

2.2 Vertical Garden by Patrick Blanc

This innovative design by French Botanist Patrick Blanc uses no soil to support plant life. The vertical Garden is still considered a living wall since the plants are grown from the outer surface outward. This wall can live indoor or outdoor, however it is currently found only on commercial buildings.

Figure 2 - Vertical Garden by Patrick Blanc

3.0 Concept Generation

The five-step concept generation method[1] was used to generate possible concepts for the design of the Living Wall. These steps include:

1. Clarify the problem,
2. Search Externally,
3. Search Internally,
4. Explore Systematically, and
5. Reflect on Solutions.

Clarification of the problem resulted in the determination of the six sub-functions: Irrigation, Monitoring, Ventilation, Structure, Vegetation, and Education. As discussed in the Living Wall Project Proposal, specific requirements were further determined for each sub-function. External searching included research, benchmarking, and patent searches. This information was compiled and discussed in the Living Wall Reference Report. Internal searching was a combination of individual brainstorming and team discussion and brainstorming. Systematic exploration consists of the following explanation and discussion of possible concepts, as well as a discussion of complete concepts and concept integration. Solutions are reflected on in Section 4.0, where they are evaluated.

3.1 Function Concepts

To fulfill the main sub-functions, a number of concepts were considered. Table X presents an overview; concepts are discussed further in following sections.

Irrigation (Distribution)	Irrigation (Material)	Monitoring	Ventilation (Space)	Ventilation (Circulation)	Structure	Vegetation	Education
Drip System: Drip tape	PEX	Electric Sensor and Data Box	Manifold Tubing	Passive Air Circulation	Square	Floral	Printed Display
Drip System: Drip line	PVC	Feel and Appearance (Human Gardener)	Space Confine-ment	Fan	Triangle	Edible	Dynamic Display
Sprinkler	HDPE	Tensiometer (Mechanical Sensor)		Air Powered Drum Pump	Hexagon	Herbal	Information Kiosk
Manual Watering					Circle	Filtering	

Table 1 - Function Concepts: Overview

[1] As presented in Ulrich Eppinger, Chapter 6 (available on Vista)

3.1.1 Irrigation

Drip System: Drip Tape
Drip tape would be buried in the soil of the wall. Emitters would be spaced evenly through out the tape allowing for the dispersion of water directly to the root system.

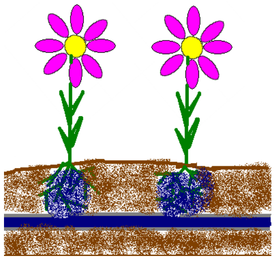


Figure 3 - Irrigation Concept: Drip Tape

Drip System: Drip Line
Drip line is very similar to drip tape in that there are equally spaced locations where the water can drip out of the line. The main difference is that the drip line is installed above surface and drips water onto the plants.

Figure 4 - Irrigation Concept: Drip Line

Sprinkler
Sprinklers would be mounted across the face of the wall and spray water on the vegetation.

Figure 5 - Irrigation Concept: Sprinklers

Manual Watering
A staff member would be required to manually water the wall regularly with a watering can or similar device.

Figure 6 - Irrigation Concept: Manual Watering

3.1.2 Monitoring

The monitoring system of the Living Wall will measure and record the water content of certain portions of the wall.

Electric Sensor and Data Box

A sensor is plugged in to the soil and records the moisture content based on the dielectric constant of the soil. The information is sent to a data box where a program interprets the data based on pre-determined moisture ranges. A signal is sent to the irrigation system if moisture levels drop below the lower limit.

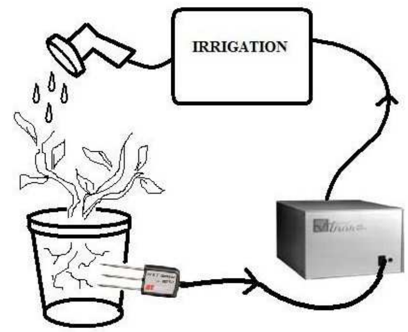


Figure 7 - Monitoring Concept: Electrical Sensor

Feel and Appearance (Manual)

An experienced hand and eye can determine the soil moisture content based on feel and appearance. Table 1 is used to help the gardener determine whether or not the plants need water.

Figure 8 - Monitoring Concept: Manual

Tensiometer (Mechanical Sensor)

A tensiometer is an airtight, water-filled device with a porous ceramic tip. It measures water tension at the tip and displays the reading on a vacuum gauge in centibars.

Figure 9 - Monitoring Concept: Tensiometer

3.1.3 Ventilation

The ventilation system of the "living wall" serves to actively draw air from surroundings across the vegetation and through the soil for contaminant break down and air exchange. All solutions generated for the ventilation system has been divided into two categories: space configurations and air circulation equipments. The first part of the structure serves to create suitable environment of air suctions.

Manifold Tubing Connection

Each cell will be connected to a manifold via pipe adaptors between the cell and manifold tubes. The air circulating equipment (such as a pump or a fan) will be coupled to the manifold which connects all the tubes from cells, and draws air from each cell.

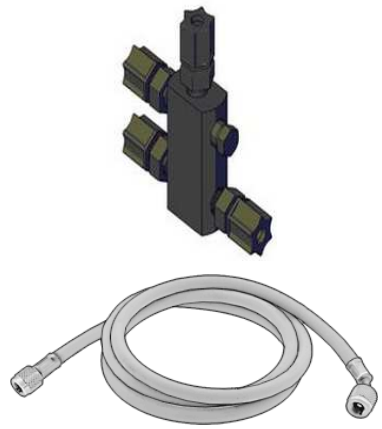


Figure 10 - Ventilation Concept: Manifold Tubing

Confinement Space

A tightly sealed confinement space will be constructed behind the wall of modular cells. The air circulation equipments will be placed inside for air suction and circulations.

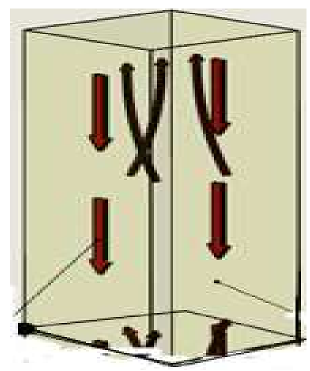
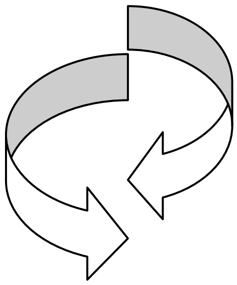


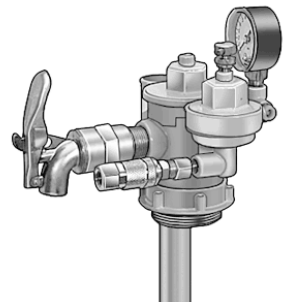
Figure 11 - Ventilation Concepts: Confinement Space

The latter part of the system serves to create negative air pressure that allows the circulation of air. Classification trees for each part are available Appendix B – Classification Trees.



Passive Air Circulation
Air passively circulates around the wall body through natural convection. However, this will not be considered in our case since a part of the functional requirement of the project is to actively improve air quality.

Fan
The revolving vanes of the fan create negative pressure and draws air flow through the wire mesh and exhausts it towards alternative openings.



Air Powered Drum Pump
The mechanical displacement of pump directs air flow through the wire mesh and exhausts it towards alternative openings.

3.1.4 Structure

The living wall system in principle is based on growing plants in an array of modular panels on a vertical surface. A range of different concepts were explored in designing the structural component of each modular panel and of the living wall as a whole. Geometric configurations were not considered which required a combination of multiple and different irregular polygonal cells as they would significantly complicate the integrity of the structure, and elevate cost. The final contending concepts for the single panel were the rectangular, circular, triangular, and hexagonal cell configurations as seen in **Error! Reference source not found.**.

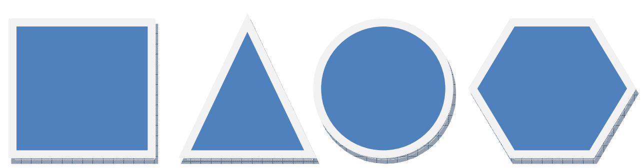


Figure 12 - Structure Concept: Cell Shapes

3.1.5 Vegetation

The vegetation system is occupies the majority of the volume of the living wall and is what will be mostly observed by viewers. Its aesthetic appearance and functional performance plays an important role in the overall presentation of the system. All potential choices of plants have been divided into two main categories: indoor and outdoor plants, with sub categories underneath. A classification tree is available in Appendix B – Classification Trees.

Outdoor plants are not considered as an option for this project, since all plants in the living wall will be growing in an indoor environment. There are numerous indoor plants to be considered that can be classified into four categories: floral, edible, herbal, and filtering (contaminant removing). The list of plants for each category includes but is not limited to the plants shown in Appendix C – Vegetation Classification.

3.1.6 Education

The following are a few primary methods of delivering the education component of the living wall. Pros and cons to each can be found in Appendix E.

Exhibition of printed information

This would be a static presentation of printed materials on the components of the living wall system, and the university's commitment to sustainability.

Figure 13 - Education Concepts: Printed Information

Dynamic Display

This method will present real-time information of the environment and performance data of the living wall via a LED display board like those at the airport terminal and bus stops.

Figure 14 - Education Concepts: Dynamic Display

Information Kiosk

This option provides both static and real-time information on a computer screen with a touch interface

Figure 15 - Education Concept: Information Kiosk

3.2 Complete Concepts

The main concepts previously discussed function as part of an overall system to fulfill the individual sub-functions as well as the overall function of the wall. Other components are required to complete these systems, as is the integration of some of the concepts and systems.

3.2.1 Complete Concept – Irrigation

In addition to the distribution of the irrigation system, and the main material that comprises the remainder of the piping, several other components are required. Water will initially be contained in a reservoir for storage, followed by a shutoff valve. When the valve is opened, water will flow through a Y-filter which both filters the water and allows the input of liquid fertilizers. A pump will provide the necessary pressure to distribute the water to the individual distribution system (drip lines, for example). Each distribution system will have a control valve to open and close the line.

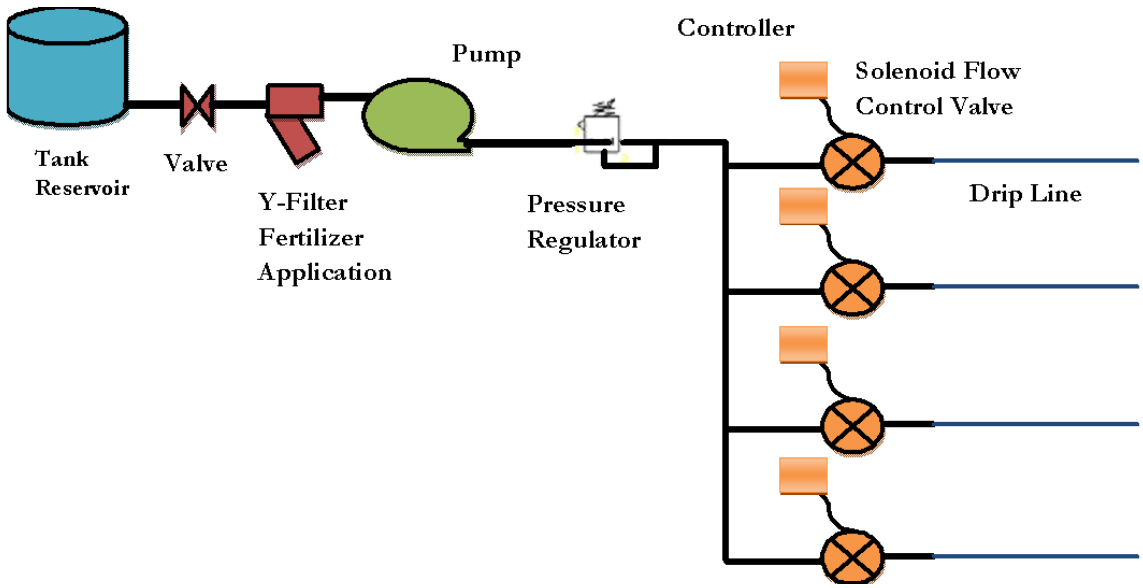


Figure 16 - Irrigation Concept: System Overview

This system and these components would be required for two of the three possible distribution concepts (drip line, drip tape, sprinklers). The fourth concept, manual watering, would not require any components of this system. As a variety of components are available, the use of this system is also independent of the material used for piping.

3.2.2 Complete Concept – Ventilation

For the ventilation system, different elements of the space configurations and air circulation will be combined into four concepts, whereas each of them will be evaluated further. The four concepts are: confined space with fan, confined space with pneumatic pump, manifold with pump and manifold with fan.

Confined Space with Fan:

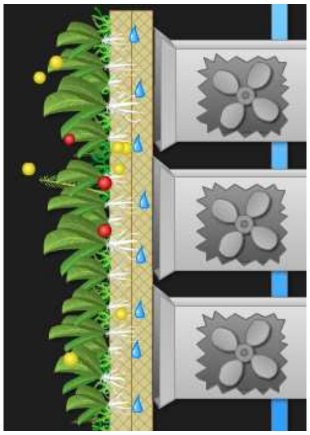


Figure 17 - Ventilation Concept: Confined Space with Fan

Gaps between each modular cell will be tightly sealed with filler, sealant materials and structural design. An air-tight, narrowly enclosed space with openings at the other end will be constructed behind the cellular wall. Electrically powered fan will be placed within the confined space to create negative pressure that directs the air flow through the wall towards the exhaustive openings. Fan is a suitable device for this application since it produces high volume and low pressure.

Confined space with pneumatic pump:

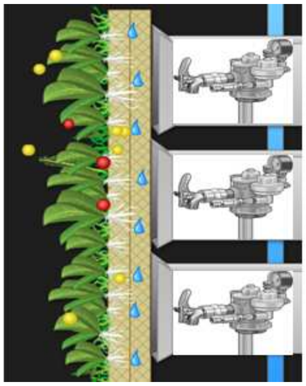


Figure 18 - Ventilation Concept: Confined Space with Pneumatic Pump

Gaps between each modular cell will be tightly sealed with filler, sealant materials and structural design. An air-tight, narrowly enclosed space with openings at the other end will be constructed behind the cellular wall. Electrically powered pneumatic pump will be placed within the confined space, where the displacement of the piston will directs the air flow through the wall towards the exhaustive openings

Manifold with Pump:

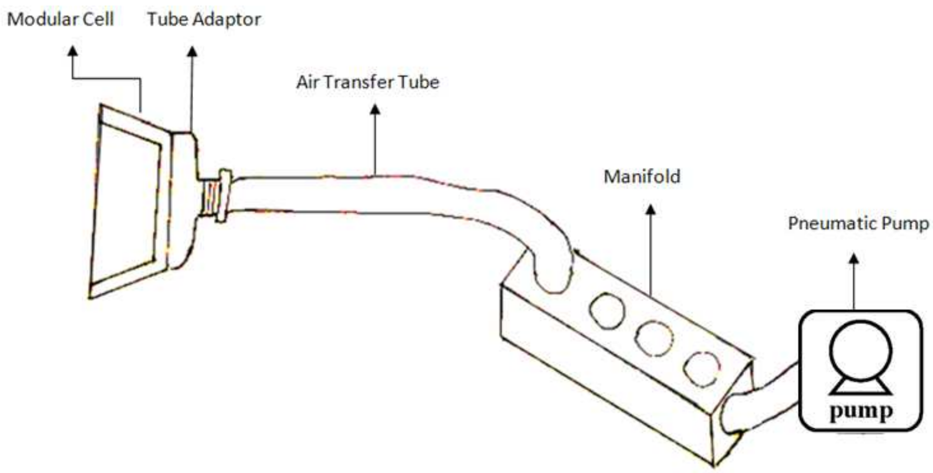


Figure 19 - Ventilation Concept: Manifold with Pump

Each modular cell will be connected to a tube threaded adaptor, which in turn connects to an air transfer tubes, then to a manifold that is connected to a pneumatic pump. Air is directed through the wall towards the exhaustive opening of the pump by the suction it creates through the tubing configuration. As opposed to a fan, pneumatic pump produces high pressures at a comparatively low volume, which makes it a more suitable device for this application.

Manifold with Fan

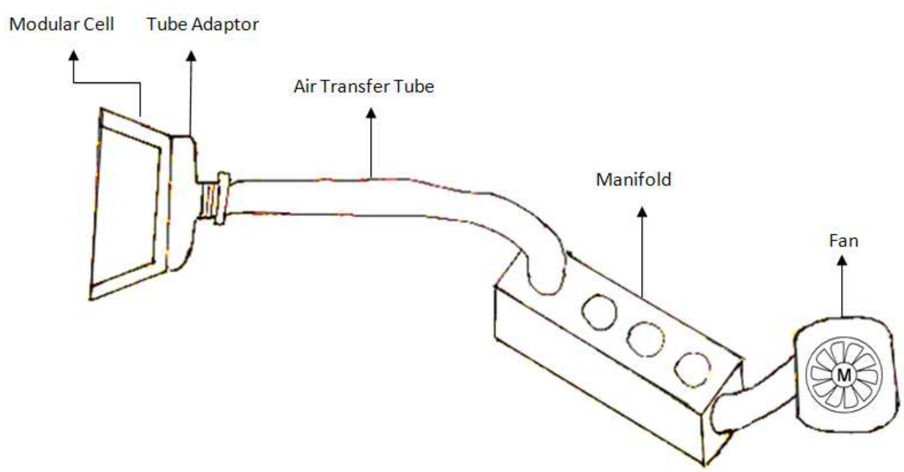


Figure 20 - Ventilation Concept: Manifold with Fan

Each modular cell will be connected to a tube threaded adaptor, which in turn connects to an air transfer tubes, then to a manifold that is connected to an electrically powered fan by adaptor. Air is directed through the wall towards the opposite side of the fan by the suction it creates through the tubing configuration.

3.2.3 Integration of the Irrigation and Monitoring Systems

The integration of irrigation and monitoring is one that cannot rely on research of existing living walls or patents for clarification. The majority of living walls using drip systems work on timers; none of the walls researched thus far have a monitoring system. The irrigation system that the team would like to implement only waters the vegetation when the monitoring system says it should. This method will ensure minimal water wastage, if any. Several problems to overcome with the integration of drip system irrigation and an electronic sensor monitoring system must be considered. Discussion of these problems can be found in Appendix F.

The integration of the drip system irrigation and monitoring can pose several unforeseeable problems as no background knowledge of the integration with living wall is know. To ensure this particular integration is not a major concern for the project, the team will construct a prototype of the two systems and perform several tests to ensure they operate together without flaws.

3.2.4 Integration of the Ventilation and Structural Systems

The ventilation system and structural systems will be working in close conjunction with one another. In order for the ventilation system to be effective, a reasonable degree of sealing must be provided for the air gaps between the structure and the cells that fit on it. This can be accomplished in a variety of manners: the use of O-rings or gaskets, caulking, and expanding foam sealant.

However, in order to ensure that we keep the system modular, cells must be able to be removed and placed back onto the structure with ease. This eliminates the caulking and foam sealant options, and leaves O-rings or gaskets (or a combination of the two) for sealing the system.

Two options that we can consider are as follows:

1) Incorporate a flange on the plant cell or on the structure to allow a gasket to be fitted on easily. (Figure 21)
2) Incorporate a groove on the plant cell to seal between the structure surface and cell surface. (Figure 22)

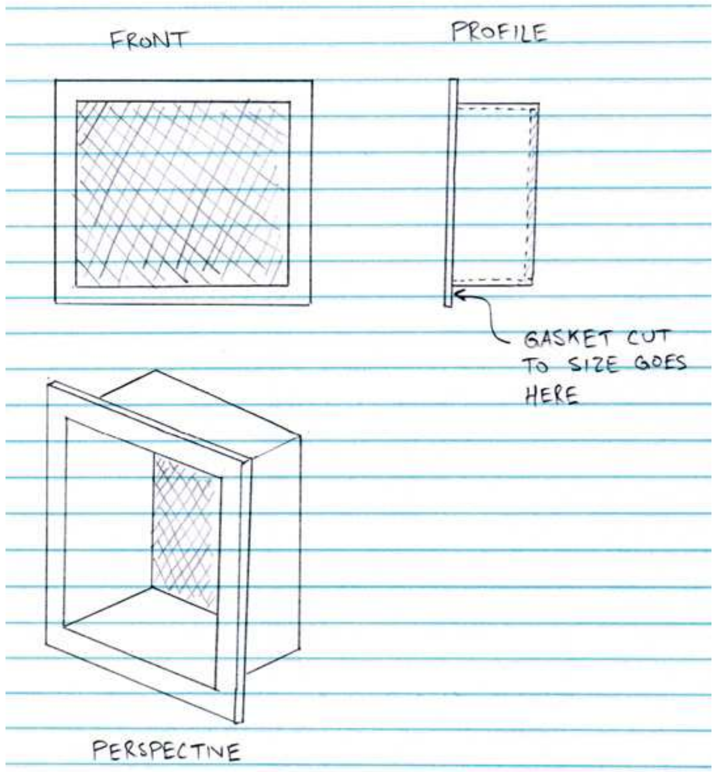


Figure 21 – Ventilation & Structure Integration: Gasket

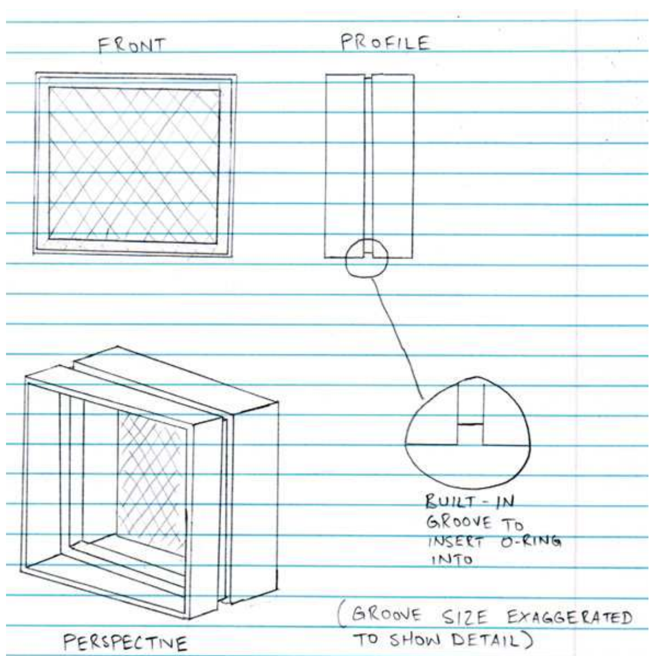


Figure 22 – Ventilation & Structure Integration: O-Ring

The figures above demonstrate possible solutions for square-shaped cells, but can easily be modified for other shapes.

4.0 Concept Selection

Two stages of evaluation were used to choose concepts to fulfill sub-function requirements. A screening process was used to determine the most viable concepts. As few concepts are considered in the first place, concept scoring was also used to confirm results or further evaluate potential concepts. Based on both screening and scoring results, concepts were chosen for further development.

4.1 Irrigation

Two components of the irrigation system must be considered; distribution devices and additional component materials.

The screening process for irrigation distribution concepts is shown in Table 2. This process provided initial direction and suggested where research effort should be concentrated. However, since so few concepts were considered, most concepts were evaluated by scoring as well. Manuel watering was removed as it cannot be autonomous.

	Min Wasted Water	Min Power Input	Minimal Space	Ease of Implementation	Ease of Maintenance	Autonomous
Drip Tape	Y	Y	Y	Y	Y	Y
Drip Line	Y	Y	Y	Y	Y	Y
Spray Nozzles	N	N	N	N	N	Y
Manuel	N	Y	Y	N	N	N

Table 2 – Irrigation Distribution Screening

Distribution concepts were scored based on cost, weight, and energy requirements in terms of pressure (Table 3). Materials for the main piping of the system were scored based on similar metrics, but include flexibility and recyclability (Table 4). See Appendix F - Evaluation Metrics for metric values and sources used to determine scoring. The highest store is considered best.

	Weight	Drip Tape		Drip Line		Spray Nozzles	
		Score	WS	Score	WS	Score	WS
Cost/Foot	0.45	3	1.35	3	1.35	1	0.25
Weight	0.30	3	0.9	2	0.6	1	0.25
Pressure Required	0.25	3	0.75	3	0.75	1	0.25
	Total Score	3.00		2.70		0.75	

Table 3 - Irrigation Distribution Scoring

	Weight	PEX		PVC		HDPE	
		Score	WS	Score	WS	Score	WS
Cost/Foot	0.35	3	1.05	2	0.70	2	0.70
Weight	0.25	3	0.75	1	0.25	2	0.50
Flexibility	0.25	3	0.75	1	0.25	3	0.75
Recyclability	0.15	3	0.45	3	0.45	3	0.45
	Total Score	3.00		1.65		2.40	

Table 4 - Irrigation Material Scoring

Based on both screening and scoring of possible distribution methods and materials, it was determined drip tape and PEX provide the best options. Drip tape provides an even distribution method at the lowest cost and weight, using the minimal amount of energy (requiring lowest pressure). PEX is recyclable and flexible, at the lowest cost and weight per length.

4.2 Monitoring

Three different monitoring concepts were discussed: an electric sensor, a human gardener, or a mechanical tensiometer. They are all forms of measuring the volumetric moisture content of the soil and relaying this information back to the irrigation system. The criteria used to compare these three concepts are based on requirements set by the SUB Wall design team: accuracy, output form, service life, variability, cost.

Table 5 shows if each concept meets the requirement set in each category. Numerical performance metrics can be found in Appendix F - Evaluation Metrics.

Monitoring	Accuracy	Output Data	Service Life	Variability
Sensor	Y	Y	Y	Y
Gardener	N	N	Y	N
Tensiometer	Y	Y	Y	N

Table 5 - Monitoring Selection: Screening

Tensiometers were not further evaluated as they do not meet all of the performance requirements. Relying solely on a human gardener for monitoring is also no longer considered.

From Table 5, it is clear that using an electronic sensor meets all of the monitoring requirements. The strongest attribute of the sensors is their ability to control the irrigation autonomously. This allows the wall to vary water use according soil moisture, not according to a timed interval. Next steps include research into different types of electric sensors to find more precise estimates on prices, accuracies, service lives, and installation information.

4.3 Ventilation

The ventilation system, as noted previously, will consist of two components: one will be to seal off the back of each cell from the environment, and the other component is what will create the negative pressure.

Table 6 shows the criteria used for the initial screening process. It was desired for the system to be quiet so it doesn't disrupt the environment around the space. Also, as sustainability is a priority, we wanted a system that would consume a very small amount of power. Finally, our third criteria was for the system to occupy a minimal amount of space.

	Quiet	Low Power	Minimal Space
Compartment + Fan	Y	Y	Y

Manifold + Fan	Y	Y	N
Compartment + Pneumatic Pump	N	N	Y
Manifold + Pneumatic Pump	N	N	N

Table 6 - Ventilation Selection: Screening

From this initial screening process, the Manifold + Pneumatic Pump option was immediately refected, as it did not meet any of the three requirements. The remaining three concepts were then evaluated on a weighted decision matrix to determine which one is most suitable for the design.

The criteria and scoring can be seen below in Table 7.

	Weight	Compartment + Fan		Manifold + Fan		Compartment + Pneumatic Pump	
		Score	WS	Score	WS	Score	WS
Cost	25%	3	0.75	2	0.5	1	0.25
Power	35%	2.5	0.875	2.5	0.875	1	0.35
Space Requirement	40%	3	1.2	1	0.4	2	0.8
	Total Score	2.825		1.775		1.4	

Table 7 - Ventilation Selection: Scoring

Based on the scoring criteria of Table 7, it was determined that the Compartment + Fan concept provide the best option. The compartment will provide the required sealing requirements in a tight space, while the fan is far more efficient than a pneumatic (piston) pump. The very low pressures (less than 3 PSI) does not warrant the use of a pneumatic pump, which is generally used in very high pressure applications, and is very inefficient due to the reciprocating motion of the pistons. On top of the space advantage that the compartment has, the one advantage that the manifold would have provided is a more even distribution of pressure, but because the pressure and flow rate of air is so small (12 cubic meters per hour, per square meter of wall), the pressure distribution effects within the compartment would be negligible.

4.4 Structure

Contending structural concepts were evaluated based on a scoring system on their merits in the following categories: aesthetics, geometric support, modularity, surface coverage, and educational value.

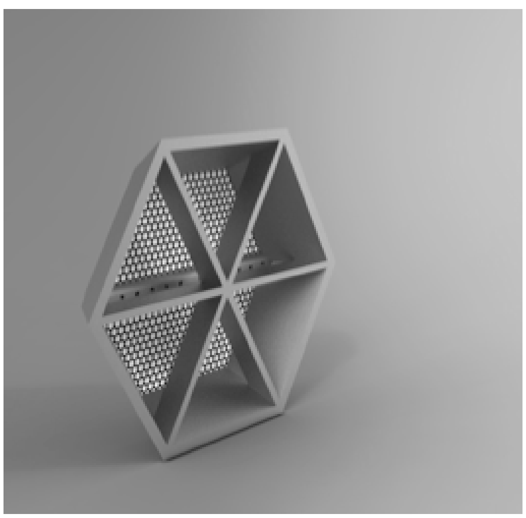
Table 8 shows the categories which each concept were evaluated on in the selection process. Each concept is awarded 2 points for adequate performance in the category, 1 point for inadequate below average performance, and 3 points for exceptional satisfactory performance.

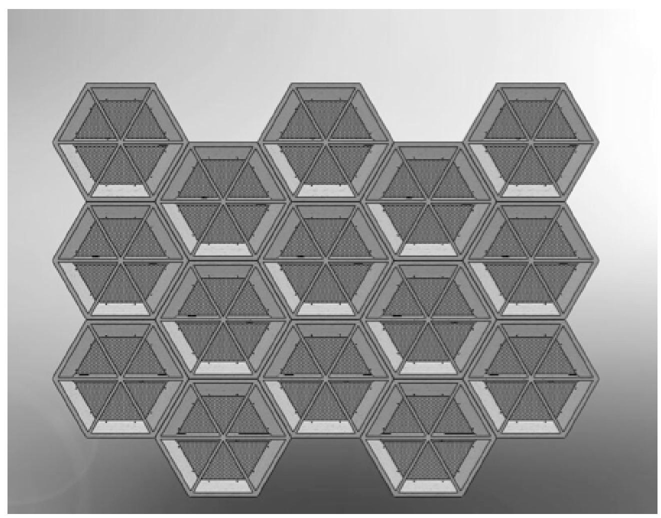
	Aesthetics	Geometric Support	Modularity	Surface coverage	Education	Total
Rectangular	2pts	2pts	3pts	3pts	2pts	11
Circular	3pts	1pts	2pts	1pts	2pts	9
Triangular	2pts	3pts	3pts	2pts	1pts	11
Hexagonal	3pts	3pts	3pts	2pts	3pts	14

Table 8 - Structure Selection: Scoring

Based on the evaluation criteria, the hexagonal configuration turned out to be is most desirable overall. Further discussion of the evaluation criteria and ratings can be found in Appendix E.

Since there is much affinity between the geometric structure of both triangular and hexagonal cells, triangular configuration will be adapted into the hexagonal cell. The final concept is composed of an array of hexagonal cell panels with triangular subdivisions to provide additional structural support and dividers for vegetation diversity. The selected configuration communicates a strong educational and sustainable message, and the application of biomimicry at the core of its design, embracing nature's strategies.





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4.5 Vegetation Selection

At this stage of the project, evaluation of the vegetation has not been preceded due to the limitation of the team's expertise in this area and priority of other subsystems. The team has come up with ten evaluation criteria for the selection of vegetations. The evaluation will be done later in the project with help from experts in the area of agriculture. Evaluation criteria include: hypoallergenic, sunlight requirements, water requirements, effectiveness in counteracting chemicals, appropriate growth rate, aesthetic appearance, functional value (ie. Edible), fertilizer requirements, seasonal adaptability, and environmental impact.

4.6 Education Selection

Again, educational concepts have not yet been evaluated or selected as other more critical sub-functions have taken precedence. As previously discussed, printed information, dynamic display, and information kiosks may all be considered. The final education method may be a combination of all three. Evaluation criteria will include metrics such as: attention-grabbing, simplicity, quality of information presentation.

5.0 Concept Validation

Validation of concepts will take place using prototyping. It is difficult to prove concepts individually, as they must all interact to form a functioning wall. Validation of irrigation, monitoring, ventilation, structure, and their integration will mostly take place during the construction and testing of a physical prototype of a 2-3 cell wall. These components will be further validated using the seven-step method, in a manner similar to that shown for irrigation.

Step 1: Define the purpose	Ensure system fits and functions properly as a whole, is accessible for service
Step 2: Choose a survey population	Small population
Step 3: Choose a survey format	Face-to-Face
Step 4: Communicate the concept	Prototype and drawings
Step 5: Measure customer response	Record suggestions and positive/negative responses
Step 6: Interpret the results	Note response statistics, frequency of suggestions
Step 7: Reflect on the results	Make changes as required and reasonable

Validation of vegetation will be based on research and the advice and knowledge of experts. Finally, education will also be validated using the seven-step method as it is the most user-interactive.

Step 1: Define the purpose	To determine the effectiveness of possible education methods
Step 2: Choose a survey population	Large; Users of the current SUB
Step 3: Choose a survey format	Face-to-Face Interaction
Step 4: Communicate the concept	Via small-scale educational components (ie. Brochures, computer displays)
Step 5: Measure customer response	Note level of understanding and level of interest
Step 6: Interpret the results	Record user statistics and opinions
Step 7: Reflect on the results	Discuss potential changes or additions to educational component

Based on prototype requirements and construction, and user responses to surveys, changes will be made as required to improve the design of the living wall and its systems.

6.0 Conclusions & Recommendations

After the evaluation of concepts using both screening and scoring, concepts were selected for irrigation, monitoring, ventilation, and structure. Vegetation and education will be further developed and evaluated as the project progresses. A drip system will be utilized with HDPE piping and associated components to distribute water to the wall. Electronic sensors will be installed to monitor the water content of the wall, to be carefully integrated with the irrigation system to ensure accurate and efficient watering. A close compartment and fan will be used to actively draw air through the wall to filter the air and break down contaminants. The structure and the ventilation system will be carefully coupled to ensure a seal, using a gasket or o-ring. The implementation of these concepts will contribute to the design of a wall that is of equal calibre to current wall systems. Successful implementation will ensure the wall has additional features, such as precise watering and modularity. To ensure that these expectations are met, concepts will be further evaluated and validated using prototypes to test for physical functionality, and the seven-step method to ensure positive user interaction.

7.0 References & Appendices

Appendix A – Benchmarking

ELT Living Wall

User Interaction:

User interaction is crucial to the ELT Easy Green design. The user is required to monitor plant life and water accordingly. Also, the user will be deciding which plants to grow in the wall. Without this interaction, the plants would obviously die and the design would fail in its overall functional requirement.

Evaluation Criteria Comparison:

When comparing the Easy Green wall to that of the SUB Wall design team, it is clear there are no ventilation or education systems to evaluate. These systems were left out from the evaluation criteria analysis.

Irrigation and Monitoring:

This design requires a user to provide irrigation and monitoring for the plants. Volumetric moisture content must be measured by feel and appearance, which typically has an accuracy of ±5-10%. Since the ideal range for typical plants is 25-35% volumetric moisture content, having such a large uncertainty makes it very difficult to keep different types of plants alive. Consequently, the user must choose plants with forgiving moisture content ranges or constantly supervise the plants.

The temperature could be better controlled in an indoor situation by assuming the plants exist in thermal equilibrium with the room. This is easy to say within ±2% making the desired interval of 15-25 ^{o}C very achievable.

Vegetation:

The cubic shape and angle of each cell combined with small groves to allow for inter-cell root growth, allows the user to pick a wide variety of plants. When choosing plants, the user is only physically bounded by the size of each cell. However, no information is provided to aid the selection of such plants.

Structure:

The supporting structure of the Easy Green Wall is made from 100% recyclable high density polyethylene, which is classified as a sustainable build material; this is backed with a 15 year material warranty.

In summary, the ELT Easy Green Living Wall performs well only under certain conditions:

1. The user must be providing active care for the plants. This includes regular watering, manually checking soil moisture content, and checking temperature levels in the room.
2. The user must select plants that do not require precise soil moisture levels to survive.
3. These plants cannot have excessive growth rates to take over the entire structure or kill other plants. Some appropriate plant types include common perennials, herbs, and small shrubbery.

Vertical Garden by Patrick Blanc

User Interaction:

Because the Vertical Garden lives only in commercial buildings, two types of users exist. The first type of user is the general public who interact with the wall as a show piece. To ensure the public does to affect the wall by touching or pulling the plants, more resilient and docile plants are used in the lower sections of the wall. The public users do not affect the wall's plant survival; however their enjoyment is the main reason for the walls existence.

The second type of user is one who maintains the wall and ensures its survival. This user is responsible for setting appropriate watering times and checking how plants are affecting one another. This requires a user with extensive plant knowledge and experience. Without this user, the plants would die, and the wall would lose fail at its critical function.

Evaluation Criteria Comparison:

Sine there are no ventilation or education systems in the design of the Vertical Garden, these sections will be left out of the comparison.

Irrigation and Monitoring:

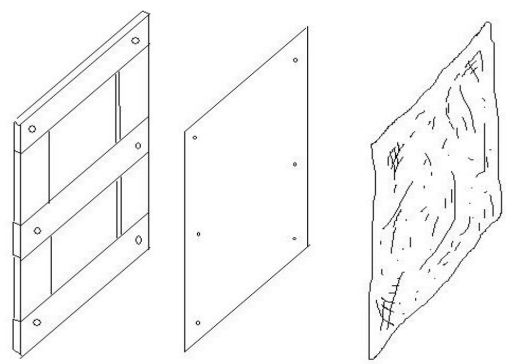
It is difficult to compare these systems to the criteria of the SUB Wall design team because no soil is used in the Vertical Garden design. The monitoring must be done visually by an experienced eye. This person should be able to judge if the plant is in need of water or not, however no information is given regarding the moisture content of the plants' roots. This makes watering a function of time rather than moisture content. As a result, a timed irrigation system is used on a best guess basis. Although effective under the right conditions, this system tends to overwater to ensure the plants don't dry out. Timed irrigation usually carries an uncertainty of ±1 day on a typical weekly watering cycle.

Vegetation:

The Vertical Garden supports very specific plant life, and extensive expertise is required in planning the vegetation and vegetation patterns for the wall. As this product is heavily copyrighted and very specific, little information is available on what vegetation is appropriate for the wall.

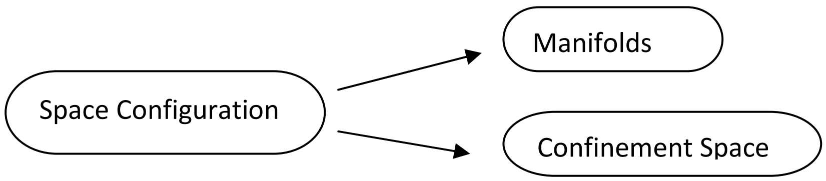
Structure:

This wall consists of a three part system which includes a supporting steel structure, a PVC layer, and a felt layer on the surface. As no soil is used, it is two to three times lighter than other living walls. Also, the wall does not have modular cells, which allows plants to grow in any direction.

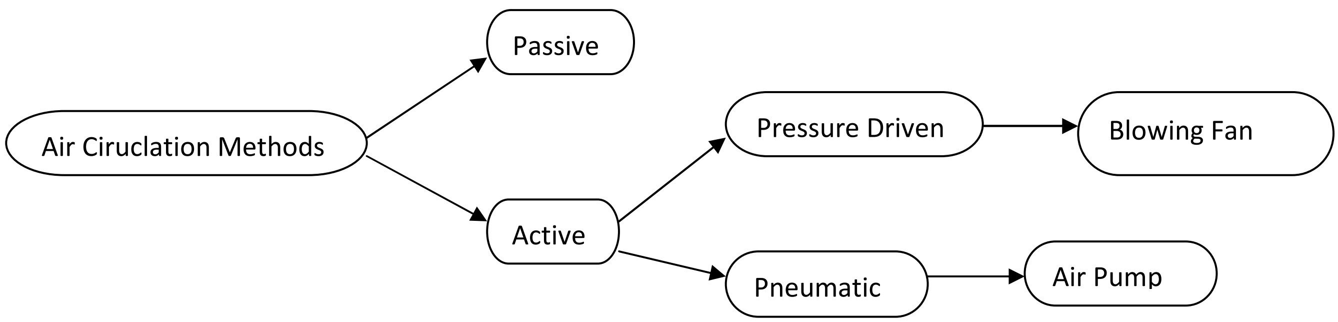


Appendix B – Classification Trees

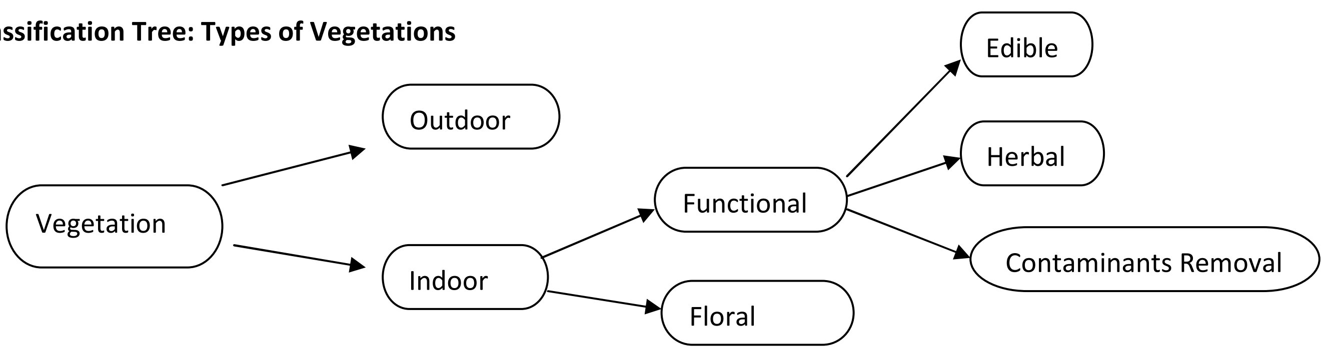
Ventilation Classification Tree: Space Configuration



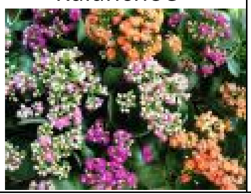
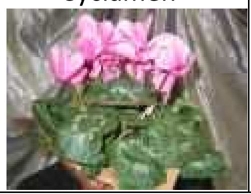
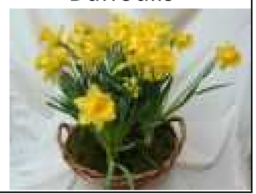
Ventilation Classification Tree: Air Circulation Methods



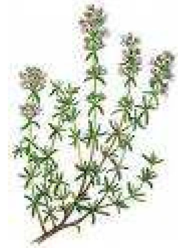
Classification Tree: Types of Vegetations



Appendix C – Vegetation Classification

Floral:				
Bromeliad 	Peace Lily (Spath) 	African Violet 	Amaryllis 	Echevaria (Hen-and-Chickens) 
Christmas Cactus 	Azalea Topiary 	Kalanchoe 	Cyclamen 	Daffodils 

Edible:				
Pineapple Guava 	Mulberry 	Cape gooseberries 	Strawberries 	Dwarf Pomegranate 
Apricot 	Tomatoes 	Grapes 	Banana 	Figs 

Herbal:				
Lemon Balm 	Mint 	Thyme 	Chamomile 	Coriander 
Fennel 	Jasmine 	Lavender 		

Contaminants Removal:				
Areca Palm 	Reed Palm 	Dwarf Date Palm 	Boston Fern 	Janet Craig Dracaena 
English ivy 	Australian sword fern 	The Peace Lily 	Rubber plants 	Weeping figs 

Appendix D – Pros & Cons to Education Methods

Exhibition of printed information

Pros:

- Low production and development costs
- easy maintenance
- flexible, scalable
- detail information
- sustainable (no power consumption)

Cons:

- Static information
- does not provide real-time feedback from the wall to the audience
- close proximity engagement, limited number of audience

Dynamic Display

Pros:

- system/environment feedback
- dynamic real-time information
- succinct information
- high visibility
- easily communicated to a bigger audience

Cons:

- consumes some power
- not effective for visuals and graphical data
- requires some maintenance of electrical components

Information Kiosk

Pros:

- interactive user engagement
- system/environment feedback
- dynamic real-time information
- multimedia content
- detail information

Cons:

- high development and production costs
- relatively high energy consumption
- single user engagement per terminal
- requires some maintenance of the hardware and its software component

Appendix E – Integration of Monitoring and Irrigation

1. Ensuring the control that receives the signal from the electronic sensor is compatible with the solenoid valves of the irrigation line.
    a. This will be addressed when the controller is purchased.
2. The time that the controller tells the solenoid valves to remain open for is accurate and will provide the correct amount of water required by the vegetation.
    a. Testing of different watering times with a prototype will need to be performed to ensure the timing is accurate.
3. The monitoring components remain dry.
    a. Careful attention will be made to the location of the wires and sensors, and if any extra protection is required.
4. Will there be a lag from when the signal to open the valves and water the plants is sent and received by the valves? If so how long will this be?
    a. Testing of when the signal is sent to when the valve actually opens can be performed once a prototype has been configured.
5. Will the signal minimum distance for the electronic sensors to the controller be the same as the solenoid valve and the controller?
    a. This will be addressed when the sensor, controller and valves are purchased to ensure the signal distances are sufficient.
6. How many controllers are needed per electronic sensor and in turn how many controllers are required per solenoid valve?
    a. The number of controllers per sensor and valve will be addressed when specing and purchasing the products.

Appendix F - Evaluation Metrics

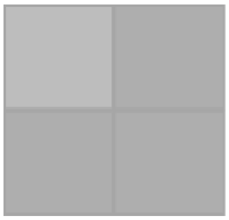
Irrigation

	PEX	PVC	HDPE
Cost/Foot ($/ft)	$0.33	$0.80	$0.40
Weight (kg/m^3)	938	1390	970
Flexibility (1 or 0)	1	0	1
Recyclability (%)	100	100	100

Monitoring

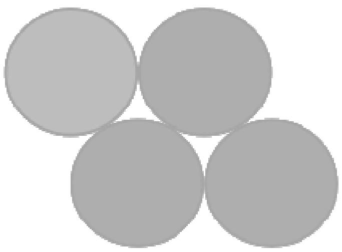
	Accuracy	Output Data	Service Life	Variability	(Cost)
Sensor	1-3%	Digital Data → Computer Control	~ 8-10 years	Instant (autonomous)	Med-High
Gardener	5-10%	Human Interpretation	Infinite	After inspect (manual)	Low
Tensiometer	3-5%	Pressure Gauge → Moisture Table	~ 10-15 years	After inspect (manual)	Med

Appendix G – Discussion of Shape Evaluation



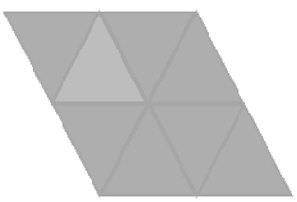
Rectangular Configuration

This arrangement of modular rectangular cells is currently the standard cell structure in most living walls. Its simplicity arrangement provides a satisfactory stable and modular structure. Its right angles allows for easy close packing of cells thus maximizing surface coverage for a concealed ventilation compartment. Although technical merits performed well, its conventional square grid formation does not provide additional ephemeral value beyond its connotation to city blocks and other urban artifacts.



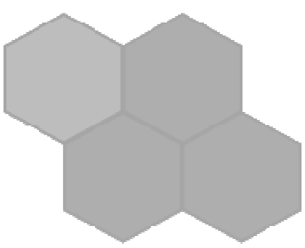
Circular Configuration

This arrangement of circular cells alluded to the organic properties of its round edges, providing a rather fresh and harmonious landscape for the cellular wall. It does however performs poorly in terms of surface coverage due to its inefficiency in concealing the space between cells, and the minimal sharing of cell edges also make this configuration a poor contender in terms of structural support, and modularity.



Triangular Configuration

The Triangular cells provide good support, modularity, and surface coverage. The angular nature of this arrangement is unconventional and does not resonate much with the natural environment, but it does however convey strongly of structural integrity and support. The triangular configuration would perform well structurally and will speak visually of its own structural properties.



Hexagonal Configuration

The hexagonal configuration provides strong structural support, good modularity and surface coverage, in terms of both public perception and actual performance. The honeycomb structure of this arrangement has myriad connotations to the natural environment and organic life, in addition to its affinity to diversity, connection and community. Its reference to carbon molecules makes it a strong contender in terms of educational and sustainable values.

Appendix L Critical Function Prototype Report

Mech 457 Capstone Design

Critical Function Prototyping Assignment

Submitted By:

Stephanie Wilson

Jordan Cowan

Jacky Ling

Brittany HIlbrecht

Wilson tran

Wen Li

Submitted On: November 30, 2009

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1.0 Introduction

For the design of the Living Wall, six sub-functions are being pursued: irrigation, monitoring, ventilation, vegetation, and education. To fulfill the requirements of the Critical Function Prototype assignment, ventilation was chosen for prototyping. This sub-function was chosen as contains the most unknown factors and variables. The plausibility of the sub-function itself, influential parameters, and optimizable parameters are all unknown. To learn about and further define the ventilation system, a prototype will be constructed experiments will be conducted.

The test setup will consist of a centrifugal fan and tunnel lab setup. A soil box will be attached to the end of the tunnel. Air will run through the fan, the tunnel, and the soil box. Pressure measuring equipment will be used to determine the pressure difference, and from this the flow velocity will be determined. Parameters such as mesh size, soil water content, and porosity will be varied.

It is expected that experiments will demonstrate the following correlations: with a higher porosity, air flow through the soil will increase; with change of mesh size, air flow will not significantly change; with greater water content, flow rate will decrease. Results will be used to determine whether active ventilation is possible in this scenario, and optimal conditions. Results are also expected to provide some indication as to the power required to run the fan.

2.0 Proposed Test Setup

The team is using the centrifugal fan and tunnel from the Kaiser 1180 laboratory. This is already set up with a variable speed fan and method of measuring pressure drop (Figure 1, Figure 2, setup dimensions as in Table 1) .

Figure 1 - Centrifugal Fan & Tunnel

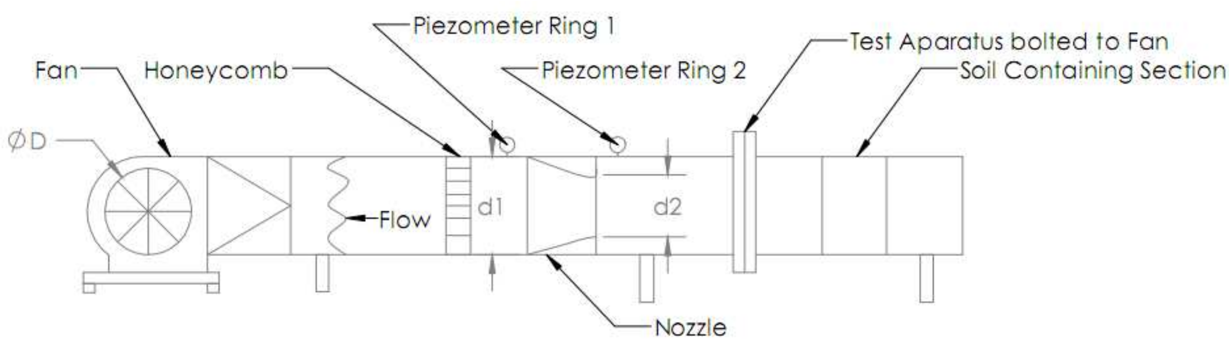

Figure 2 - Centrifugal Fan & Tunnel Schematic

Fan System Dimensions	
Fan	Size
Wheel Diameter D	0.311 m
Duct diameter d1	0.308 m
Nozzle Diameter d2	0.216 m

Table 1 - Setup Dimensions

A rectangular box with two open sides will be bolted on to the existing tunnel. Soil is placed in the box and mesh fabric is stapled on to the two open sides. Several different mesh fabrics will be tested to determine how they affect air flow, an example of mesh parameters is given in Table 2.

Material Type	Stainless Steel
Stainless Steel Type	Type 304
Form	Woven Wire Cloth
Shape	Sheets

Woven Wire Cloth Tolerance	General Purpose
Mesh Size Range	Fine Mesh
Mesh Size	250 x 250
Square/Rectangle Size	.0024"
Wire Diameter	.0016"
Percentage of Open Area	36
Sheet Width	12"
Sheet Length	12"

Table 2 - Mesh Parameters

Also, the team will observe if soil is falling out of any of the mesh grids (ie: if the mesh openings are too small or large). The box must be sealed using a silicone or air sealant tape (Figure 3) to reduce the number of air leaks. The box will be held together by screws and glue. Medium Density Fibre wood was chosen for the box material because it is easy to work with and is cheap.

Figure 3 - Air Sealant Tape

The pressure difference caused by the soil box will be measured using an inclined manometer. The pressures can be read directly off the manometer. Readings may need to be scaled, depending on the incline of the device. The incline can be used to improve the resolution of the reading.

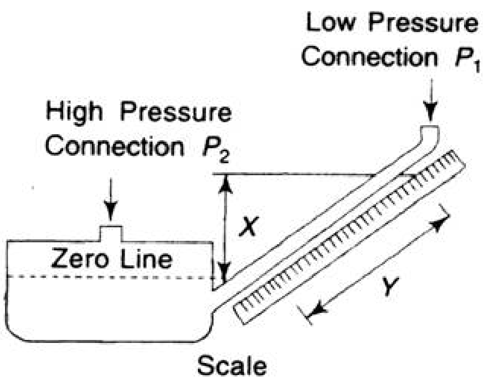

Figure 4 - Manometer

Materials required for the construction of the prototype itself (soil box) are listed below. A schematic of the box and the air flow through the system are shown.

Part	Material	Price
Main Box	½ inch MDF	$15.83
Mesh	Stainless Steel	$15.50
Mesh	Plastic	$5.49
Kiwi Sealant	Latex	$2.19
Potting Soil	-	$5.49

Table 3 - Bill of Materials

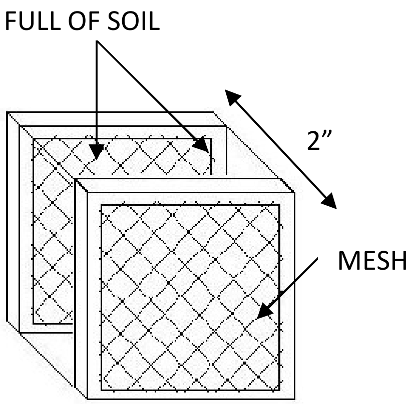

Figure 6 - Soil Box

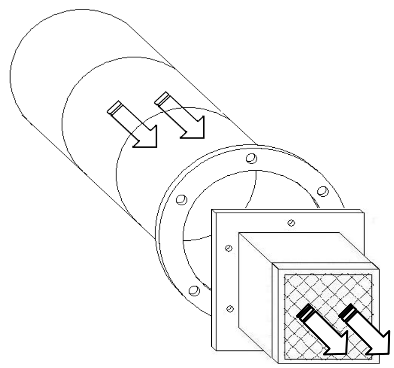

Figure 5 - Air Flow through Setup

3.0 Proposed Experiments

In the process of prototype testing, we wish to experiment with a combination of a variety of meshes, soils and water content, in order to determine the air flow characteristics for each setup. From this we will determine the best candidates for the finalized ventilation system design. Experiments will be conducted as shown below in Table 4.

List of Experimental Setups			
Test #	Mesh Size	Water Content (% volume)	Amount of Perlite (% volume)
1			
2			
3			
4			
5			

Table 4 - Experiments

Some meshes used may include stainless steel mesh, bug screen mesh, and landscaping fabric. Water content will be varied by percent volume. Porosity of the soil will be varied by the amount of perlite included and mixed into the soil. Experiments will be conducted as described below.

Experimental Procedure:

1. Set up the test apparatus with the desired type of soil, mesh and water content specification
2. Ensure the test apparatus is supported at the same height as the fan. Bolt the test apparatus Figure 6 to the end of the test fan Figure 5.
3. Seal any possible gaps between the fan the apparatus using air sealant tape Figure 3.
4. Ensure the inclined manometer Figure 4 is leveled by adjusting the base screws.
5. Turn on the power supply to the fan
6. Adjust the fan to the desired speed. Allow it to run for at least 2 minutes to achieve steady state flow.
7. Once steady state flow is achieved, record the manometer Figure 4 values (pressure of the duct, P_{duct}, and pressure difference between the duct and nozzle, ΔP) in the table below. Please make note of the unit of measurement for the pressure readings.
8. Repeat steps 1 to 7 for the remainder of the test setups.

Setup #	P_{duct}	ΔP	Fan Speed (RPM)
1			
2			
3			
4			
5			

Table 5 - Data Records

4.0 Expected Results

From conducting the experiments, we expect that:

- With a greater volume (in terms of percentage) of perlite (within the soil, there will be a greater flow rate of air through the soil
- With the change of mesh size, there should not be a significant change in flow rate
- With a greater water content, the flow rate will be reduced

Figure 7 - Perlite (http://images.bidorbuy.co.za/user_images/651/390651_Perlite1.jpg)

Because the perlite (Figure 7) is a porous material, having a greater volume of it mixed into the soil should effectively make the soil more porous, thus reducing the resistance to air flow.

The differences in mesh sizes should cause changes in air flow as well, where a courser mesh allows a greater amount of flow, and a finer mesh restricts the flow more. However, its effect on the airflow should be minimal in comparison to the effect from the soil, simply because the mesh is so thin, and the mesh size is much larger in comparison to the gaps between the soil particles.

Adding water to the soil should effectively fill in the gaps between the soil particles, and effectively reduce the porosity, and thereby reducing the air flow.

From this procedure, we are hoping to determine the effects from the different mesh sizes, as well as the effects from different perlite and water content levels within the soil. Data from the experiments will be analyzed in a spreadsheet, shown below in Table 6.

Ensure that manometer fluid is known prior to performing experiment, to correctly determine the pressure difference

Test Apparatus Cross-Section Width (inches)	9	**Soil Depth (in)**	2
Test Apparatus Cross-Section Height (inches)	9	**Soil Depth (m)**	0.0508
Test Apparatus Cross-Section Width (m)	0.2286		
Test Apparatus Cross-Section Height (m)	0.2286		
Test Apparatus Cross-Section Area, (m^2)	0.052258		

Enter P1 and P1-P2 Values below

Setup #	P_{duct} (Pa) P1	ΔP (mm) P1-P2	ΔP (Pa)	**Q (m^3/s)**	**q [(m^3/s)/m^2]**
1	1	2.00	15.65982	0.210705	4.032010901
2			0	0	0
...	...	...	...	...	...

Table 6 - Experiment Analysis

5.0 Analysis & Next Steps

After our tests have been performed and sufficient analysis has been completed, the team will need to evaluate the results to decide the next steps. The ventilation system was chosen to prototype first, as it is the component requiring the most information.

The most important results the team will be able to take from the experiments are whether or not the ventilation system is possible and practical. If air can flow through soil under conditions required by the vegetation system then further research into active ventilation should be completed. However, if the medium/soil completely blocks any air flow then the team will need to re-evaluate the experiments completed, to see if anything was missed or decide that the active ventilation should be removed from the project scope.

Assuming the experiments result in some sort of flow across the medium/soil, the specific results from each test will need to be evaluated individually and as a whole, to optimize the conditions.

5.1 Different Porosity Percentages

The different mediums/soils will be in terms of different porosities; the higher the porosity percentage the more air pockets available in the medium/soil. An optimum value of porosity percentage and air flow will have to be determined by graphing the results. Once this optimal percentage has been obtained, a larger quantity of the specified medium/soil will be purchased for further testing with regards to the remaining systems of the living wall.

5.2 Different Mesh Sizes

The medium/soil will need to be contained in a way that the airflow does not send the mixture flying away from the structure. A way of containing the medium/soil is to use a mesh on either side. By testing different mesh sizes, the team will be able to determine which size mesh will not block the airflow while still being able to contain the medium/soil.

5.3 Different Moisture Levels

The medium/soil will not be completely dry when used in its final application; therefore, different moisture levels will be tested to ensure airflow would still be possible during irrigation. Further research will need to be conducted to ensure the range of moisture levels needed by plants is known. If the water concentrations required by the vegetation restricted flow substantially in the tests ventilation may not be achievable.

5.4 Power Requirements

Each experiment conducted to find the optimal medium/soil porosity level, mesh size, and moisture level will have to be further analyzed to determine if the power requirements to obtain those values is anywhere achievable. It must be determined if the power requirements outweigh the benefits of actively passing air through the medium/soil.

The living wall's main requirement is sustainability. If the ventilation requires too much energy to run at optimal parameters then ventilation will not be feasible. However, the research and testing completed will still provide the team with significant information which can be used by the other sub systems of the wall. The mesh size, water moisture and soil porosity are constraints that will be used for the overall structure and irrigation systems, should the ventilation system be implemented or not.

6.0 Conclusion

The experiments that will be conducted and the data that will be gathered are essential to this project. Determining whether or not further resources and energy should be put into the development of the ventilation system will be based on the results of this prototyping exercise.

The use of a variety of mesh sizes will confirm whether or not mesh size is important, and what effect it has on the system. As the cost of meshes varies with size and material, this information can be used to optimize the cost of the mesh component. Water content data will show whether or not the ventilation system can be effective, assuming the plants are watered regularly. Porosity information is essential to determining the soil that must be used; this will play a large part in determining what plants can be installed in the wall. Finally, experiments will show how much power is required to run the ventilation system; this can be weighed against the benefits the system may provide.

The prototyping exercise will be conducted as soon as possible to guide the further design of the system. Completion of these experiments will determine whether the system will be implemented or not, and allow optimization of the design.

7.0 Works Cited

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Appendix M Technical Analysis Report

SUB Living Wall

MECH 457 Capstone Design

Technical Analysis Report

Stephanie Wilson

Brittany Hilbrecht

Wen Li

Jordan Cowan

Wilson Tran

Jacky Ling

Date Submitted: Monday, January 25th

Word Count: 2067

(including figures and tables, not appendices)

Abstract

The Alma Matter Society (AMS) requested the design of a Living Wall system to be installed in the new Student Union Buiding (SUB). The purpose of this document is to define the parameters of the Living Wall structural and irrigation systems. The physical design parameters of individual cells such as area and depth are defined. The forces applied to the structure and the expected displacement are calculated and given. The irrigative material (felt) is characterized through experimentation and used to size the supply trough and collection tank. All calculations and experimental data is included in appendices. These parameters will be further defined following this report based on prototyping exercises. A failure mode effects analysis is also conducted to attempt to avoid high-risk failures.

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1.0 Introduction

The design of a living wall was requested by the Alma Matter Society (AMS), to be located in the new Student Union Building (SUB). The requirements of this project were discussed and defined in the Living Wall Project Proposal documentation. Background information and research of similar systems was discussed in the Living Wall Reference Report. Based on these documents and design work, the project was refined to its current state.

The wall itself will be supported by a skeletal structure of columns, capable of supporting several cells directly attached to it. The columns will be anchored to the building wall for further support. Horizontal beams will ensure the stability of the wall, but will not assist in upholding the structure. The cells will be backed by an irrigative material (felt), and a rigid cover (between the felt and the support structure) to prevent water from escaping the system. The felt will absorb water from a trough positioned at the top of the structure; excess water will drain into a collection tank at the bottom of the structure. This excess water will be pumped back up into the supply trough as required to continue to supply the wall with water. The soil in individual cells will absorb water from the felt as the plants require. In this manner, water will not be wasted but the plants will always have sufficient water.

Design parameters of the individual cells, structure, and irrigation system must be explored and analyzed to optimize the design of the systems and their interactions. Cell design is based on the requirements of the plants and soil, as well as convenience and practicality of size and form. The design of the structure necessitates calculation to ensure safety and adequate support for the physical components of the wall. In order to improve sustainability and reduce costs, the irrigation system must provide adequate water to the plants and allow the excess water to be recycled for future use. As the irrigation felt is difficult to analyze, the parameters of the irrigation system and felt were explored mostly through experimentation.

The specification of trivial components such as bolts was not considered for the purpose of this report. The major components and design considerations are defined and discussed, extraneous details are provided in the appendices.

2.0 Cell Design

The wall is composed of a grid of hexagonal cells (Figure 1). Each cell is further composed of 24 triangular compartments (Figure 2). Triangular components are used to more evenly distribute the weight of the soil in each cell, to limit compaction of the soil. The size and depth of the triangular compartments is based on recommendations by an industry contact[1] and to accommodate the soil containment mesh[2].

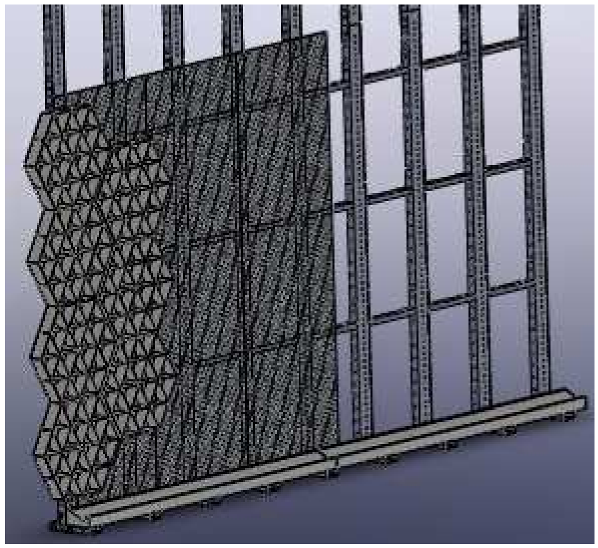

Figure 1 - Wall Cutaway

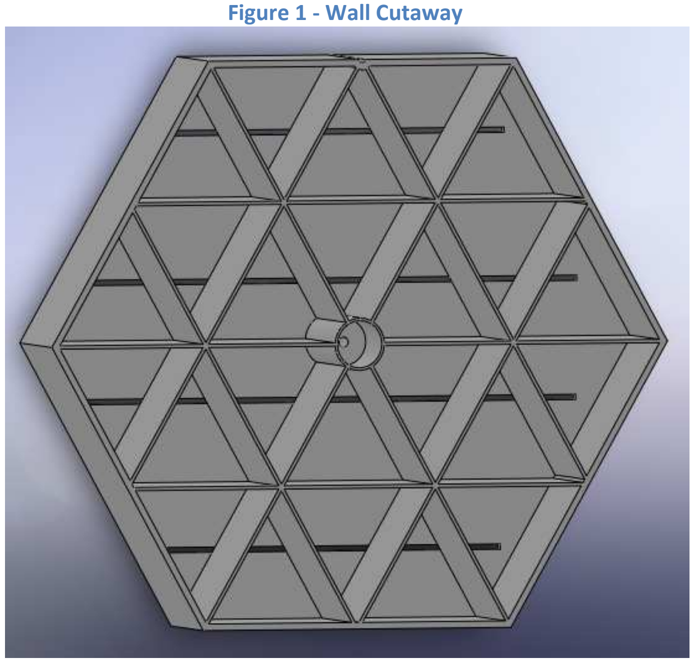

Figure 2 - Cell Structure

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[1] D. Justice, Personal Communication, November 25, 2009.

[2] http://www.gardensoxx.com/

Cells were modelled in Solidworks for analysis and ease of design changes. Technical drawings of the cell structure can be found in Appendix 7.1. The parameters of the cell are as follows in Table 1.

Weight of cell	7.92 pounds
Volume of cell material	230.36 $inch^3$
Surface area of cell material	2401.91 $inch^2$
Density of Cell Material	0.03 pounds per in^3
Surface area of Triangular compartments	15.74 in^2
Depth of triangular compartments	3.15 inch

Table 1 - Cell Parameters

Based on wet and dry soil densities (Appendix 7.4), the weight of the entire cell can be concluded to range from approximately 30 to 50 pounds. The variation in weight is mostly due to the varying water content of the soil. To take into account a safety factor, an upper cell weight limit of 80 lbs will be used for analysis.

The cell will be held onto the wall by a single bolt in the center of the cell, and a small pin at the top of the cell to ensure no rotation. The pin will not support any force; the bolt will support the 80 lb weight of the cell.

3.0 Structural Analysis

Structural support for the cells of the living wall will be provided by columns. Cells are bolted directly on to the column; the column is bolted directly onto the wall and floor of the containing building. To understand the flow of forces in the structure of the wall, a schematic of the physical system can be considered (Figure 3).

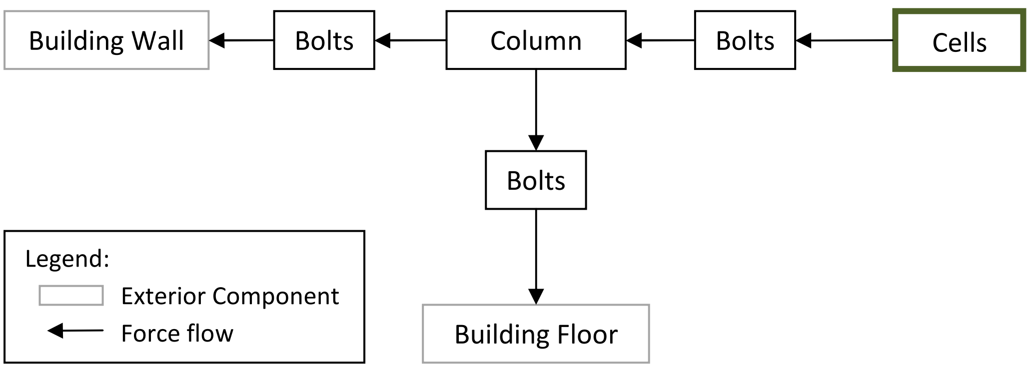


Figure 3 - Structural Schematic

To ensure the safety and structural integrity of this system, forces on the bolts and column must be considered. Forces on the building wall and floor are also estimated for the benefit of building designers. The entirety of this analysis can be found in Appendices 7.2 and 7.3.

For a wall with a height of 25 cells, as shown in **Error! Reference source not found.**, the displacement of he column due to the distributed weight of the cells is shown in **Error! Reference source not found.**. The corresponding stress up the column is shown in Figure 5. The maximum displacement, at the top of the column, will be no greater than 0.205µm (0.008 thou). The maximum stress due to the bending moment due to a buckling motion will be no greater than 2453Pa (571 lbf).

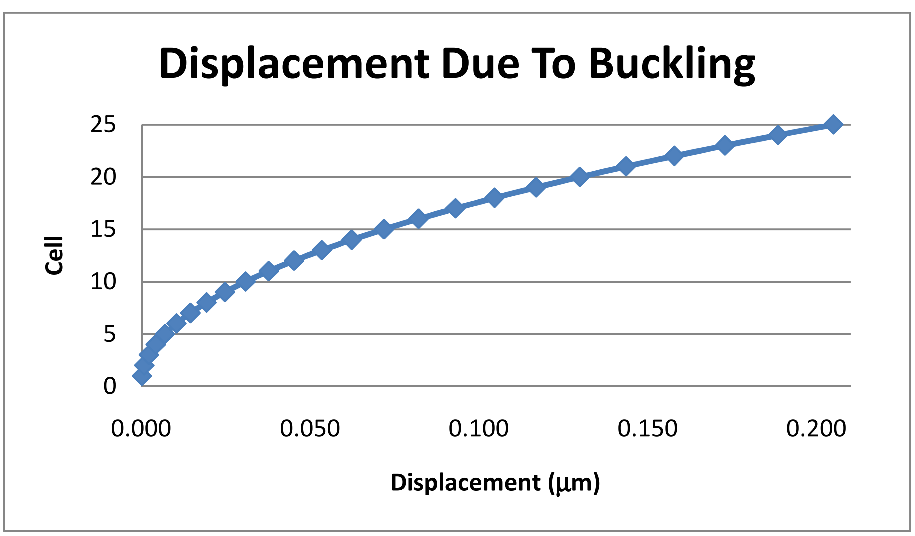


Figure 4 - Column Displacement

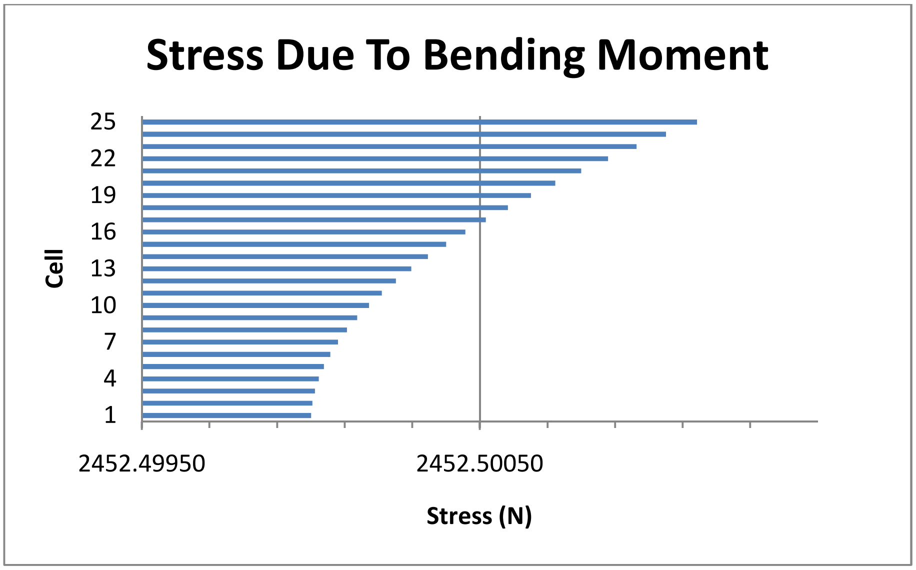


Figure 5 - Bending Stress

The compressive force on the column, which is transferred to the floor of the building was found to be 8918N (2004 lbf).

To consider the forces that bolts between the building wall and the column might be subjected to, a single bolt was considered. If the column was held to the building wall with a single bolt, the force will vary based on the position of the bolt. Figure 6 shows the force seen by a bolt positioned at various heights on the column, excluding the effect of any other force or bolt between the wall and column.

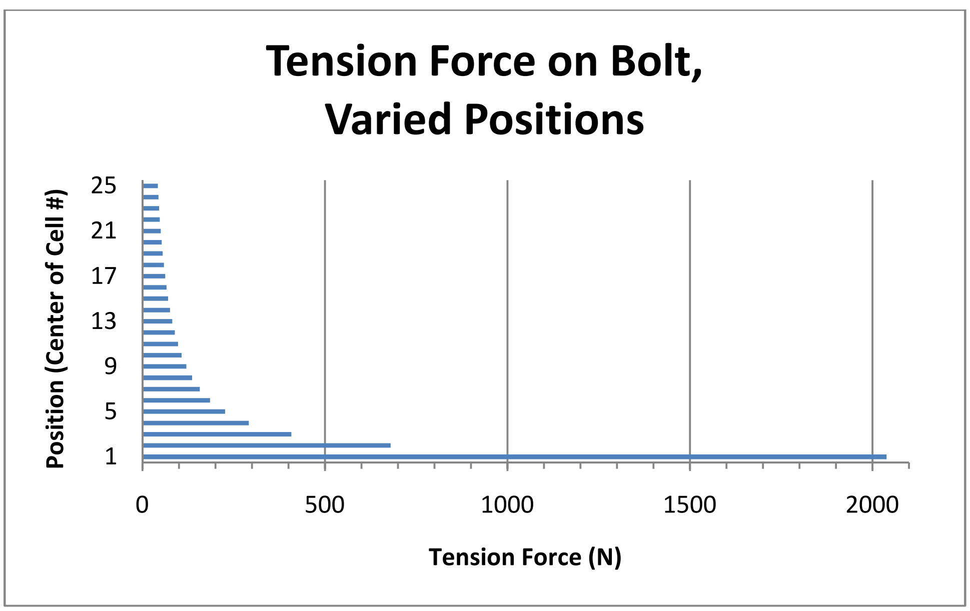


Figure 6 - Bolt Tension

The maximum force seen by a bolt could be 2038 N (458 lbf), were it positioned at the lowest cell on the column. The lowest force expected on the bolt is 42 N (9 lbf).

These analyses were carried out for the worst-case scenario, using the upper cell weight of 80 lbs, assuming only a single bolt. However, the single bolt will be assisted and the column will be further restricted from buckling and compression by multiple bolts.

4.0 Irrigation Analysis

A schematic of the irrigation system assists in understanding the flow of materials and signals (Figure 7). Water from the trough is absorbed by the felt and consequently by the plants. Excess water from the felt accumulates in the collection tank. From the collection tank, it will be returned to the trough by the pump, or drained from the system if the tank becomes full. A sensor checks the trough and turns on the pump when needed. If the collection tank is empty, the sensor opens the source tank valve to fill the trough.

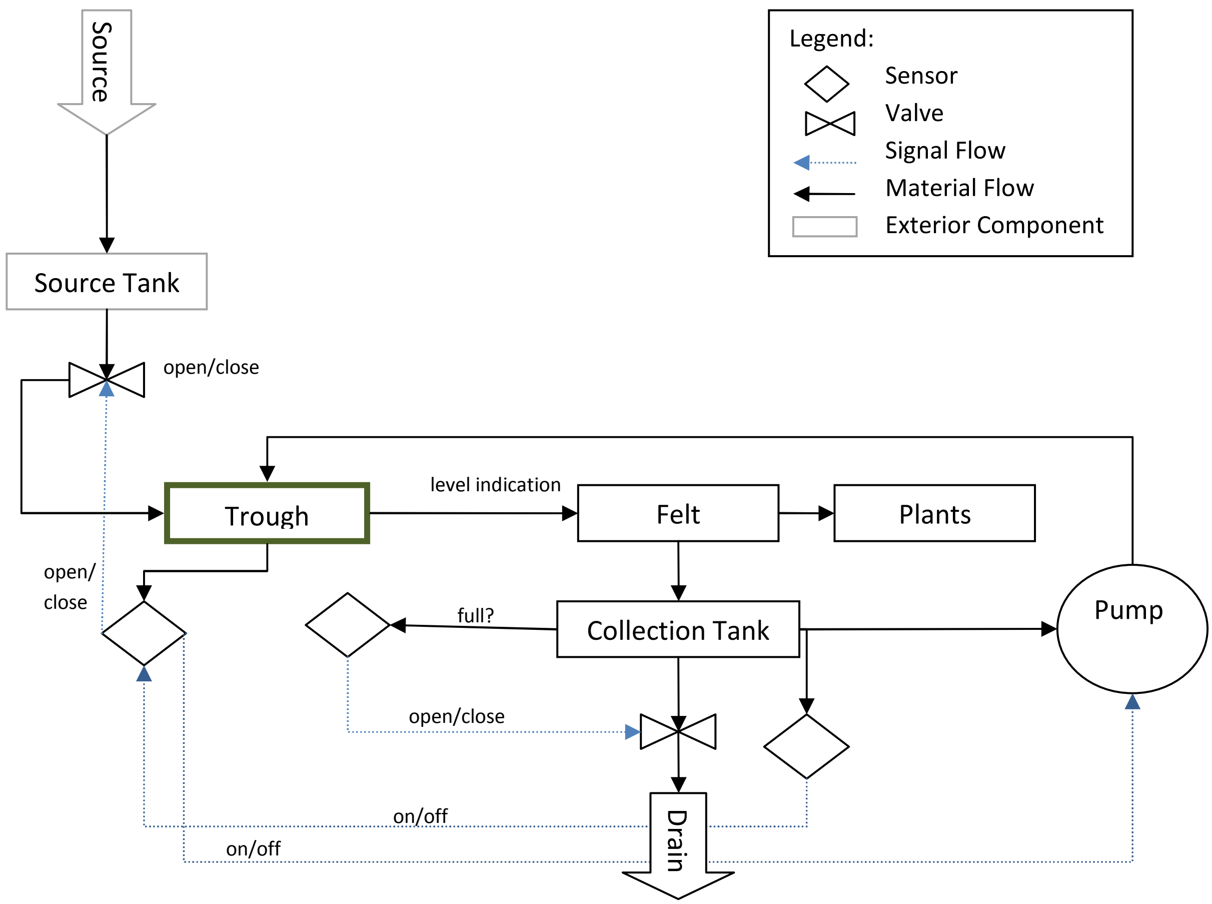


Figure 7 - Irrigation Schematic

The major components of the system have been determined; trivial components such as sensors, drainage, and exterior components such as the source have not been considered for the purpose of this analysis. The details and calculations for all results can be found in Appendix 7.4.

4.1 Flow Rate

Experiments to compare a trough placed at the bottom and top of the felt. When the trough was positioned at the bottom of the felt, the water travelled no further than 1.5 inches up the felt. When the trough was positioned at the top, if the water was less than 1.5 inches from the rim of the trough, the water quickly travelled down the felt.

There are several parameters that could change the flow rate of the water through the felt, including density, width, and length of the felt. As the density of the felt is assumed to be approximately uniform (with a constant thickness of 1/8 inches), analysis was carried out to determine how the length and width of the felt piece affect the flow rate.

Experimentation based on various lengths of felt showed that it does not affect the flow rate. The flow rate linearly increases with the width of the felt. The flow rate through the felt is approximately 0.083 gpm/foot width. Experimental data was extrapolated to suggest flow rates for a full-sized wall (Figure 8). For a wall of 30 foot width, a flow rate of approximately 2.5 gpm is expected.

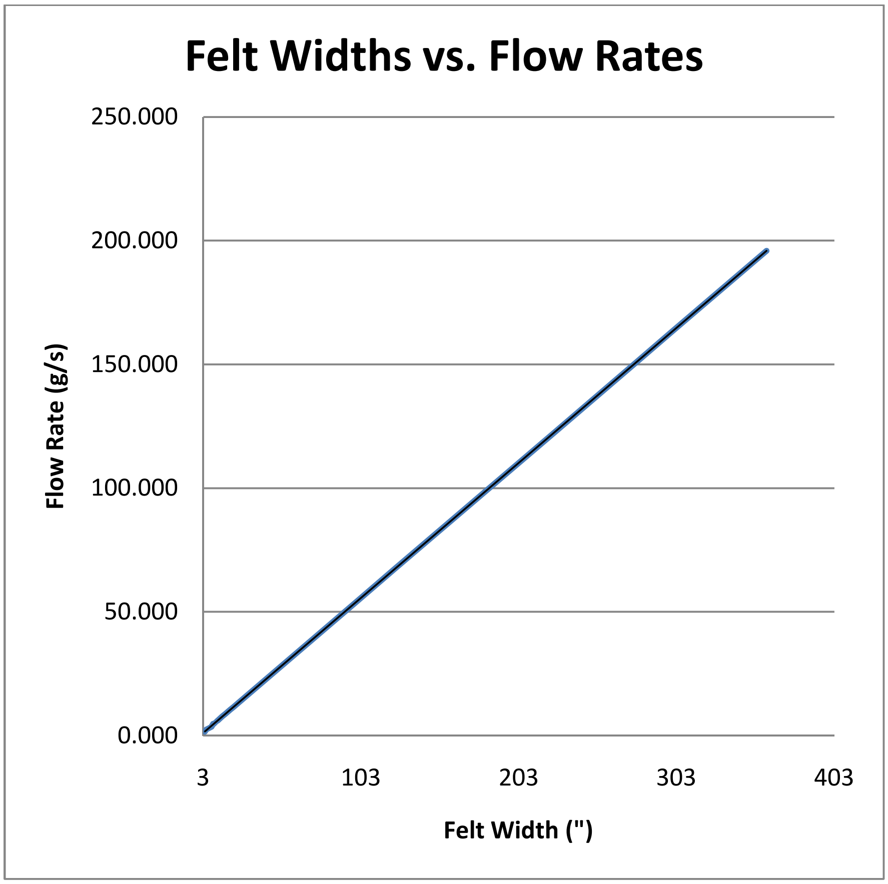


Figure 8 - Felt Width Effect

As this flow rate is large, measures were taken to reduce the flow rate. The most effective measure was found to be reducing the length of felt exposed to the source water. When the length was reduced by 50%, the flow rate was also reduced by half. Experimental conclusions are that length is not a factor in flow rate, but the flow rate is linearly related to the width of the felt exposed to the water. It is important to note that the reduction in felt length exposed to water must be evenly distributed to produce a finger-like appearance, to ensure uniform water content in the felt.

4.2 Drying & Absorption

Experimentation showed that the plants held approximately 45-55% water by weight, fully saturated. It further showed that the plants lost an average 0.28% of initial water content per hour. This information can be used to ensure that enough water is supplied, based on the amount of plants the wall supports.

The parameters of the felt with regard to water absorption and drying time were also explored. It was found that the felt could be dry for up to one hour, after which it would fully reabsorb water. After 2.5 hours, the felt was resistant to reabsorption. The period in between is unknown, based on various factors (Figure 9).

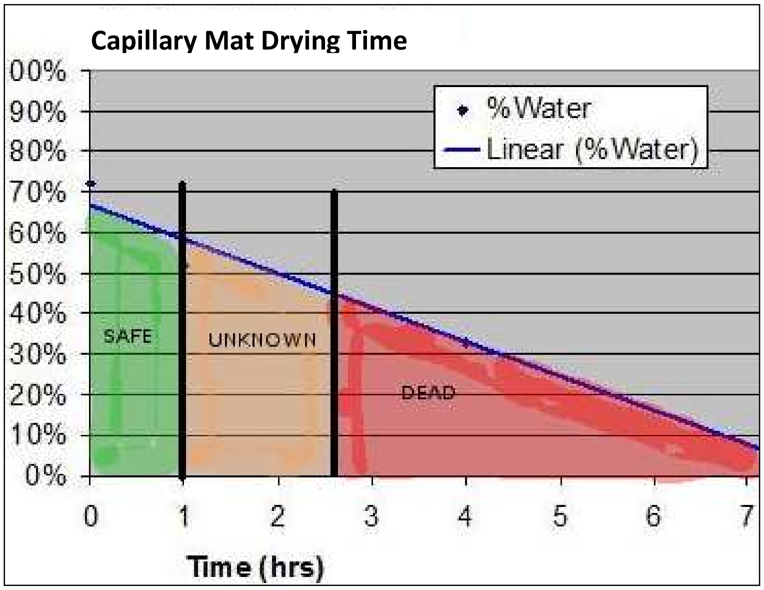


Figure 9 - Felt Parameters

Based on the drying rate of the plants, and the amount of water the plants can hold, the amount of water that must be available to the felt can be determined. This volume of water dictates a trough size of cross-sectional area 10cm by 9cm. The collection tank at the bottom of the wall will be 10 cm by 15cm high, to ensure that all water can be held in case of a system failure (Appendix 7.4).

5.0 FMEA

For the purpose of risk management, an FMEA (Failure Modes and Effects Analysis) was conducted to ensure all potential failure modes were considered. The full FMEA can be found in Appendix 7.5. Based on the resulting RPN (risk priority number), mitigation measures will be considered and may be implemented to reduce RPNs. Mitigation measures are suggested below in Table 2 for the four highest rated failure modes.

Failure Mode	RPN	Mitigation Measures
Living wall skeleton structure to structural wall connections break	72	Bolts specified with a safety factor of 2, regular inspections.
Structural Beam (vertical or horizontal) collapses	64	Beams specified with a safety factor of 2.
Bolt connecting cell to skeleton structure comes loose	49	Regular inspections of structure and connections, safety factor provided by extra bolts.
Recycling pump breaks down	48	Holding tank drain in case of overflow, regular inspections of pump and irrigation system.

Table 2 - FMEA Mitigation Measures

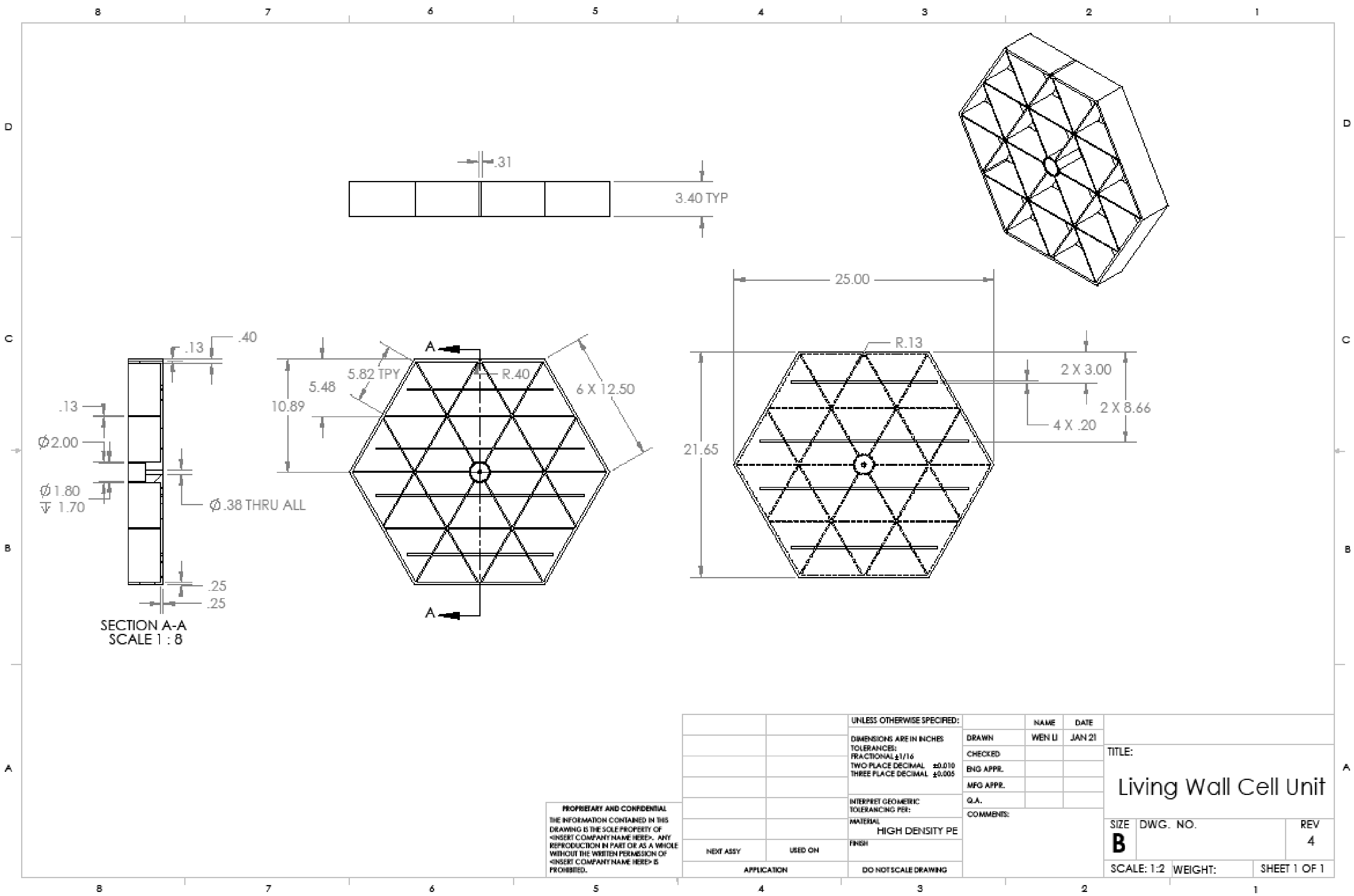
6.0 Conclusions

For a wall of approximately 30 feet wide and 36 feet high, about 144 hexagonal cells will be supported, each with 24 sub-divisions. The columnar structural beams will support the weight of the wall without yielding to bending stresses or buckling, and without significant displacement. The felt will yield a flow rate of approximately 1.25 gpm, where fifty percent of the material exposed to supply water is removed. The upper supply trough will be of cross-section 10cm by 9cm, the lower collection tank will be of cross-section 10cm by 15cm. Trivial components of the system have yet to be specified.

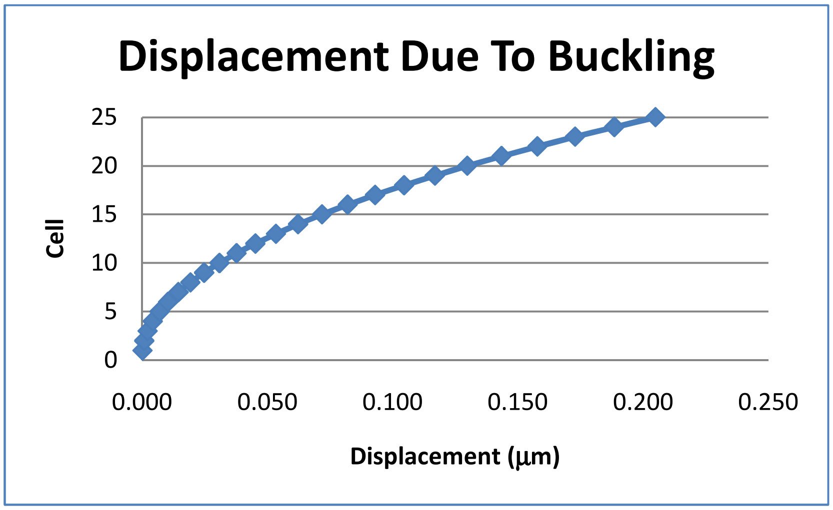
These parameters will ensure the system can adequately support the wall and its vegetation. These concepts and design variables will be further refined through prototyping, and will be altered as necessary to produce a physical model of the system. Based on the prototyping process and final prototype, the design will be finalized before submission to the client.

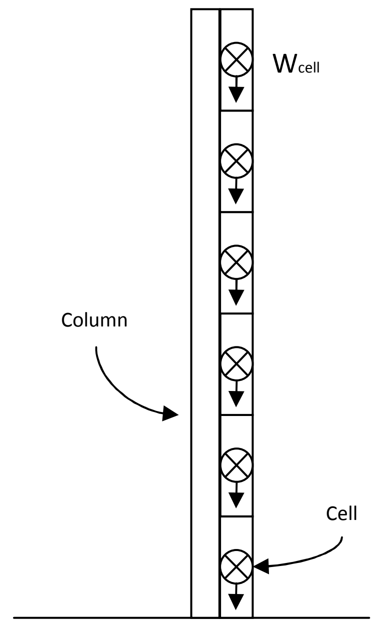
7.0 Appendices

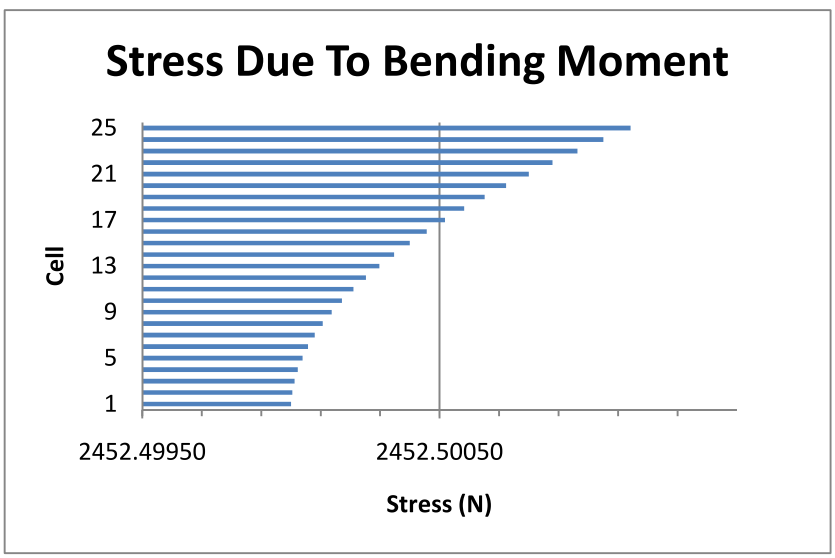
7.1 Cell Drawings



7.2 Structure – Buckling Analysis







Cell Height	0.35	m
Cell Depth	0.08	m
Mass of Cells	36.36	kg
Weight of Cells	356.73	N
Width of Column	0.40	m
Depth of Column	0.4	m
Young's Modulus Column	2E+11	Pa
Moment of Inertia Column	0.0128	m^4
Area of Column	0.16	m^2

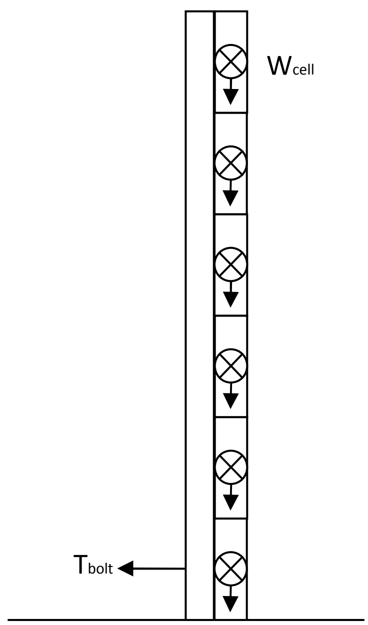
Compressive Force	8918N
Displacement	2.05E-01 μm
Max Stress	2453 Pa

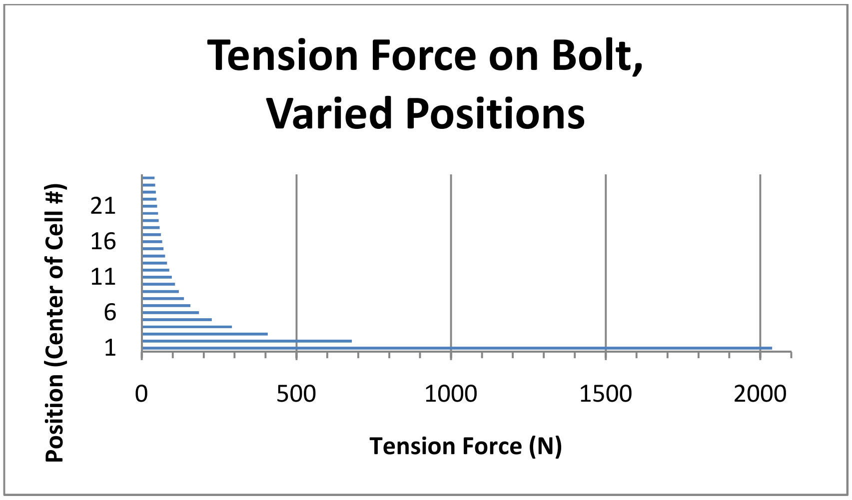
Cell	**h (m)**	**L_eff (m)**	**F_y (N)**	**y_max (μm)**	**sigma_max (Pa)**
0 -> bottom cell	dist from bottom to center of cell	effective length, h*2	force in y-direction	distance column buckles	max stress due to moment
1	0.175	0.35	356.73	0.000	2452.50000
2	0.525	1.05	356.73	0.001	2452.50000
3	0.875	1.75	356.73	0.002	2452.50001
4	1.225	2.45	356.73	0.004	2452.50002
5	1.575	3.15	356.73	0.007	2452.50004
6	1.925	3.85	356.73	0.010	2452.50006
7	2.275	4.55	356.73	0.014	2452.50008
8	2.625	5.25	356.73	0.019	2452.50011
9	2.975	5.95	356.73	0.025	2452.50014
10	3.325	6.65	356.73	0.031	2452.50017
11	3.675	7.35	356.73	0.038	2452.50021
12	4.025	8.05	356.73	0.045	2452.50025
13	4.375	8.75	356.73	0.053	2452.50030
14	4.725	9.45	356.73	0.062	2452.50035
15	5.075	10.15	356.73	0.072	2452.50040
16	5.425	10.85	356.73	0.082	2452.50046
17	5.775	11.55	356.73	0.093	2452.50052
18	6.125	12.25	356.73	0.105	2452.50058
19	6.475	12.95	356.73	0.117	2452.50065
20	6.825	13.65	356.73	0.130	2452.50072
21	7.175	14.35	356.73	0.143	2452.50080
22	7.525	15.05	356.73	0.158	2452.50088
23	7.875	15.75	356.73	0.173	2452.50096
24	8.225	16.45	356.73	0.189	2452.50105
25	8.575	17.15	356.73	0.205	2452.50114

7.3 Structure – Bolt Tension Analysis

The structural column supporting the cells is bolted to the building wall to ensure it remains upright and for further support. To determine the tension force that the bolts will be subjected to, various positions of a single bolt were considered. If a single bolt supplied a tension force at the center of a cell, the tension force on the bolt can be found as shown in a free body diagram below. The tension force applied to the bolt decreases as the position of the bolt increases (increasing position being a higher cell).

The maximum force was found to be 2038 N, if the bolt were positioned at the lowest cell; the minimum force was found to be 41 N, if the bolt were positioned at the center of the highest cell. The tension force for a given bolt position is shown on the following page. Calculation parameters and calculated results follow.





Cell Height	0.35	m
Cell Depth	0.08	m
Mass of Cells	36.36364	kg
Weight of Cells	356.7273	N
Width of Column	0.4	m
Depth of Column	0.4	m
Young's Modulus	2E+11	Pa
Moment of Inertia	0.0128	m^4
Area of Column	0.16	m^2

Position bolt position, bottom to top	**h(m)** dist from bottom to center of cell	**T (N)** tension force on bolt	**Position** bolt position, bottom to top	**h(m)** dist from bottom to center of cell	**T (N)** tension force on bolt
1	0.175	2038.442	14	4.725	75.49784
2	0.525	679.4805	15	5.075	70.29109
3	0.875	407.6883	16	5.425	65.75618
4	1.225	291.2059	17	5.775	61.77096
5	1.575	226.4935	18	6.125	58.24119
6	1.925	185.3129	19	6.475	55.09302
7	2.275	156.8032	20	6.825	52.26773
8	2.625	135.8961	21	7.175	49.71809
9	2.975	119.9083	22	7.525	47.40562
10	3.325	107.2864	23	7.875	45.2987
11	3.675	97.06865	24	8.225	43.3711
12	4.025	88.62789	25	8.575	41.60085
13	4.375	81.53766			

7.4 Experimental Data

7.4.1 Experiment: Soil Density Approximation

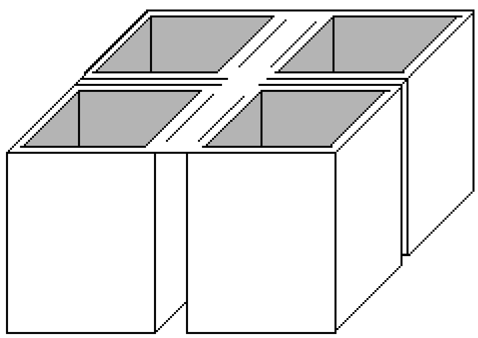
Hypothesis:

Plants are weighed and the soil container volume is measured to get a density value. This value is applied to our cell volume to get our cell weight.

Materials:

1 plant per box, 4 boxes per container

<u>1 box</u>
L = 5.5 cm
W= 3.5 cm
H = 4.0 cm



Data:

Empty container = 12 g
Plant weight – wet = 302 g
Plant weight – dry = 158 g

Calculations:

Volume of each soil box = 5.5cm x 3.5 cm x 4.0 cm = 77 cm^3

Soil density when wet = (302-12)g / (77 cm^3 x 4) = 0.942 g/cm^3

Soil density when dry = (158-12)g / (77 cm^3 x 4) = 0.474 g/cm^3

Our cells have 24 triangles and each triangle is 800 cm^3

Min cell weight (using dry density) = 0.474 g/cm^3x 800 cm^3 x 24 = 9.1 kg $\approx$ 20 lbs

Max cell weight (using wet density) = 0.942 g/cm^3x 800 cm^3 x 24 = 18.0 kg $\approx$ 40 lbs

Conclusion:

The material that the plants sit in is estimated to be about 10 lbs per cell. Therefore the weight range per cell is 30-50 lbs. Since this is just a rough estimate we are using a safety factor of 1.5. This makes the range used in calculations 45-75 lbs. This measured value will be confirmed with researched soil density values.

7.4.2 Experiment: Trough Position

Hypothesis

If trough is placed at the top of the felt, more water will be absorbed and transferred than if trough is at the bottom.

Method

Two setups:

1. Trough placed at top, felt clipped onto edge of trough with edge submerged in water.
2. Trough placed at bottom, felt clipped on top, lower edge submerged in water.

Felt pieces were same-sized, height of 48”, width of approximately 6”.
Troughs were filled with equal amounts of water at the same time, to the top lip of the trough.

Materials

2 troughs
2 pieces of same-sized felt
2 equal amounts of water
Clips

Observations

Very quickly, the water in the lower trough travelled up approximately 1.5 inches. The water in the upper trough almost immediately travelled down the length of the felt and out the bottom.

Data

Observations were almost instantaneous, and no data was taken. After 45 minutes, the water from the lower trough had not travelled any higher than 1.5 inches up the felt.

Conclusions

The trough must be positioned at the top of the felt section. If the trough is located at the bottom, the water cannot overcome gravity and the obstacle the felt provides sufficiently to travel up the felt. If the trough is located at the top, the water travels quickly through the felt.
Further experimentation must be completed to determine how quickly the water travels down the felt.

Summary Table

Summary table of data and results, only relevant data, for body of report

7.4.3 Experiment: Flow Rate: Various Widths & Lengths

Hypothesis:

The flow rate should be directly proportional to the width of the capillary mat, and have no correlation to the length.

Materials:

-two 4” x 15” capillary mats
-one 4” x 9.5” capillary mat
-one 4” x 20” capillary mat

-one 4” x 24” capillary mat
-two 2L containers
-electronic scale
-stop watch
-clothes pins

Method:
For each setup listed in the data table below, perform the following procedure:

1) Fill one 2L container up with water so water level is 2cm from the top edge, and place the container on the edge of a table
2) Place electronic scale on the floor below the water-filled container, place the second 2L container on the scale, then zero the scale
3) take capillary mat and soak it with water, allowing excess amount to drip out back into the water-filled container
4) hang the capillary mat over the edge of the water-filled container so that 4 inches is inside the container and the rest is directly above the empty container on the floor
5) use clothes pin to secure the capillary mat to the container
6) allow water to start dripping into bottom container for approximately one minute to ensure steady-state flow to be reached
7) simultaneously zero the scale and start timing
8) stop the timer when 500g on the scale has been reached, and based on the time, record teh flow rate to the data table

Data:

Test Setup	Flow Rate (mL/min)	Notes
4" Width, 11" Overhang Length	86.96	-
2 x 4" Width, 11" Overhang Length	171.43	Used two pieces of 4" width felt - approx. double the single width, as expected
4" Width, 5.5" Overhang Length	92.6	-
4" Width, 16" Overhang Length	105	-
4" Width, 20" Overhang Length	*50.93*	*This result doesn't appear to correlate at all with the other 4 results*

Observations:
With the exception of the 4” width and 20” overhang length setup, it appears that the flow rate depends solely on the width of the capillary mat used and not the length. It would appear that the 4” x 20” setup simply experienced some unseen flow constrictions within the fabric itself. Otherwise, the other four tests performed are consistent to one another within experimental error. However, it is fine for the flow to be slower and choose a pump based on the maximum measured flow. If the flow is far slower in reality, it will just reduce the frequency of pumping cycles.

Calculations:
1 gram of water = 1 mL of water
Determining the required amount of pump flow:
Given a 30 foot wall width, we can extrapolate the width of the fabric and determine the flow rate as a result. We will use the largest measured flow to ensure we size the pump at least enough for that.

Required flow = (30 feet) * (12 inches/foot) * (105 mL/min/4 inches of fabric) = 9450 mL/min
Or 2.496 Gallons per minute
Taking double that as a safety measure, we have a required **flow rate of 5 gallons per minute** from the pump, and gaining 36 feet of elevation.

Conclusion:
Based on our experiment, we determined that we would need a pump capable of providing 5gpm of flow and approximately a 36 foot gain in elevation.

7.4.4 Experiment: Flow Rate: Various Felt Widths

Hypothesis

The greater the felt width the larger the flow rate will be.

Method

Three different felt widths were tested to find their specific flow rates by pre-soaking the ends of the felt to a level lower than the water level. The flow rate was evaluated once the felt was fully soaked and a constant flow rate was evident. This was found by finding how long it took for the bottom trough to contain a given number of grams of water. The flow rate was then averaged for trials of the same felt width. A graph to display the relationship between felt width and flow rates is shown below. The felts were tested with the same lengths and felt length submerged in the water to have all other parameters except felt width held constant.

Materials

Felt of different widths
Scale
Timer
Two Troughs (top and bottom)

Observations

Two tests were done for each felt width to see how repeatable the tests were. The results showed small differences. As the felt width increases the flow rate also increases. The relationship between the felt width and flow rates seem to be exponential.

Conclusions

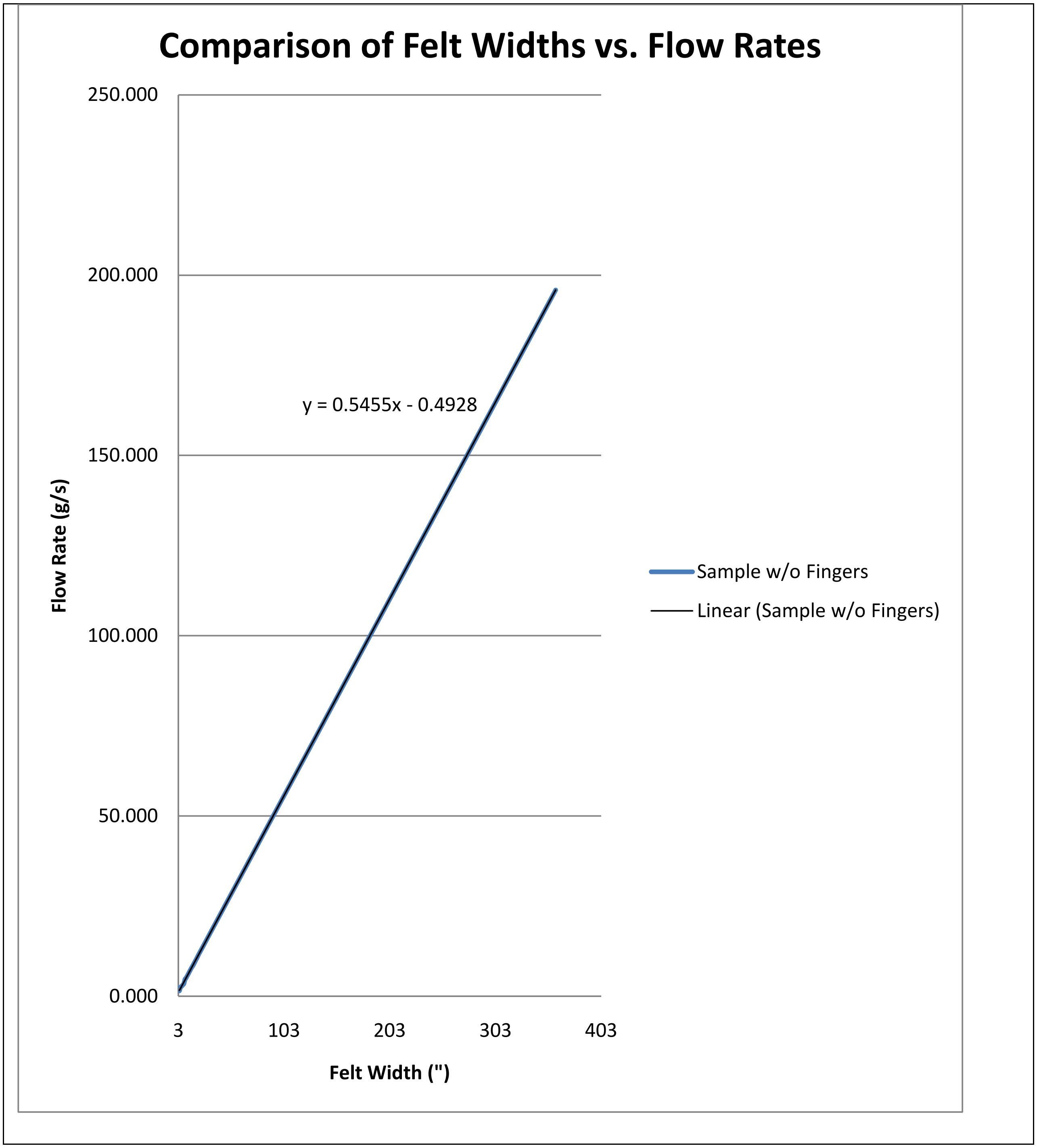
Several tests were done to achieve enough data to find an equation for the relationship between felt width and flow rates. This relationship was found to be linear. The equation was then used to extrapolate for a larger felt width equal to a wall of 30ft wide. The flow rate found for a felt width of 30ft is 3.1gpm.

Calculations

Approximate equation of the line is equal to $y = 0.5455x - 0.4928$. Data was extrapolated using the previous equation to find the flow rates for a felt width equal to a wall of 30ft.

Summary Table

	Felt Width (")	Felt Width (ft)	Time (s)	Weight Difference (g)	Flow Rate (g/s)	Average Flow Rates (g/s)
	4	0.3333	60	86.96	1.44933333	
	4	0.3333	120	171.43	1.42858333	
	4	0.3333	60	105	1.75	
	4	0.3333	60	92.6	1.54333333	1.543
Experimental Data	4.75	0.3958	137.4	270	1.965	
	4.75	0.3958	73.1	200	2.736	
	4.75	0.3958	79.2	195	2.462	2.388
	8	0.6667	98.6	380	3.854	
	8	0.6667	60	182	3.033	3.444
	9.25	0.7708	77.3	400	5.175	
	9.25	0.7708	60	270	4.500	4.837
Extrapolated Data	10	0.8333				4.962
	11	0.9167				5.508
	12	1				6.053
	15	1.25				7.690
	17	1.4167				8.781
	20	1.6667				10.417
	22	1.8333				11.508
	25	2.0833				13.145
	100	8.3333				54.057
	125	10.417				67.695
	150	12.5				81.332
	200	16.667				108.607
	225	18.75				122.245
	275	22.917				149.520
	300	25				163.157
	360	30				195.887



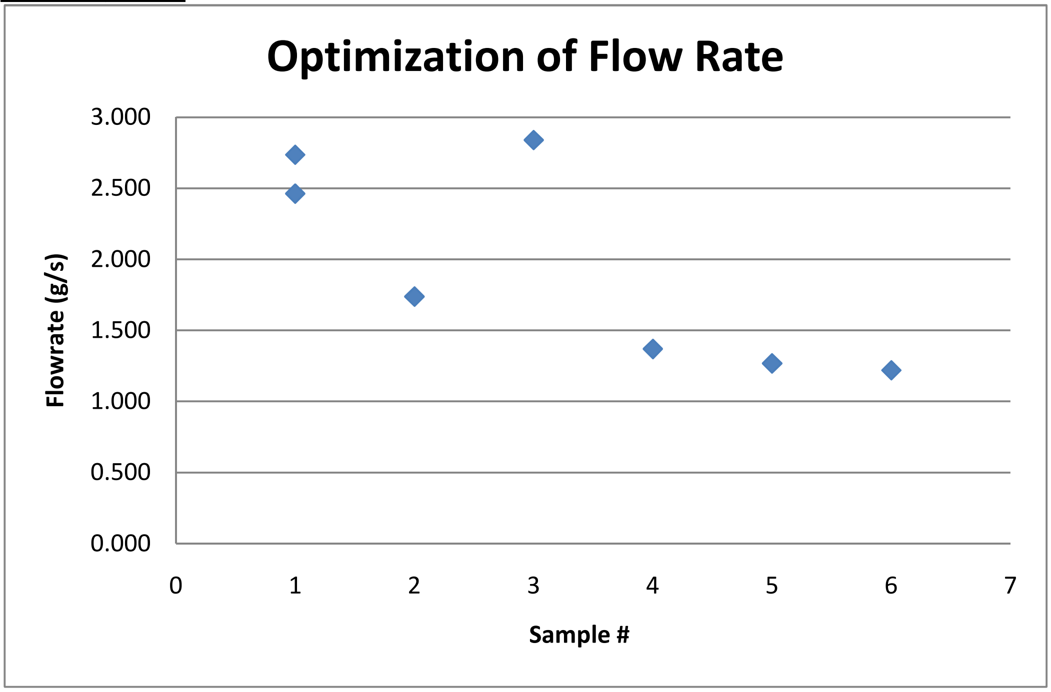
7.4.5 Experiment: Optimization of Flow Rate

Hypothesis

Decreasing the surface area submerged in water should decrease the flow rate through the felt.

<u>Method</u> A control felt was tested first to see what the original flow rate is without modifications. The control felt was tested twice to ensure its number was accurate. In all cases the felt was pre-soaked and timing started once there was a constant flow rate. Modifications such as clamping the end, cutting out sections of the width (fingers), different finger lengths were tested to see their influence on the flow rates.
<u>Materials</u> Felts with different initial surface areas Scale Two troughs Timer
<u>Observations</u> When the test with the clamps was running there was a constant flow of water coming out the bottom of the felt. With all other tests there were drips of water; proof that the clamped test resulted in a higher flow rate. The clamps also caused the felt to float on the service and not sink to the side of the trough, this should be looked into further if the orientation of the felt in the water plays a role on the flow rate.
<u>Conclusions</u> Several different variations were tested to see if the flow rate could be minimized. The smaller the flow rates the better, as long as there was an even absorption throughout the width of the felt. The test with clamps on the end resulted in increasing the flow rate, where the tests with fingers or pieces cut out seemed to decrease the flow rate. The length of the fingers also seemed to have a positive relationship on the flow rate. Another experiment on different finger lengths should be done to see if there is a minimum value that can be achieved. I don’t believe extrapolating the data will work for finger length; there must be a min value.
<u>Calculations</u> The only calculation was weight/time = flowrate

Summary Table



Sample 1: Control sample 4 ¾" square with no changes
Sample 2: Three fingers 1" long, varying widths
Sample 3: 10 clamps used to squish end
Sample 4: Five fingers 1 ½" long, ½" wide
Sample 5: Five fingers 2" long, ½" wide
Sample 6: Five fingers 2 ½" long, ½" wide

Sample #	Finger Length (")	# of Fingers	Weight (g)	Time (s)	Flowrate (g/s)
1	n/a	n/a	200	73.1	2.736
1	n/a	n/a	195	79.2	2.462
2	1	3	143	82.3	1.738
3	n/a	n/a	220	77.5	2.839
4	1.5	5	115	84	1.369
5	2	5	125	98.6	1.268
6	2.5	5	100	82	1.220

Further Calculations

50% removed for fingers will decrease the flow rate.
Below is data collected for several different tests on a 4 ¾” wide piece of felt w/ 50% fingers. After several tests were completed it was approximated that the finger length did not impact the flow rate. The flow rates of all the experiments were averaged for a 4 ¾” wide piece of felt.

Data for Felt of 4 3/4" Width			
Felt w/o Fingers		Felt w/ Fingers	
Finger Length (")	Flowrate (g/s)	Finger Length (")	Flowrate (g/s)
0	2.74	1	1.33
0	2.46	1	1.26
0	1.97	1.5	1.37
Average	2.39	2	1.27
Std. Dev.	0.39	2	1.2
		2	1.21
		2.5	1.22
		2.5	1.37
		3	1.45
		3	1.23
		4	1.38
		4	1.33
		Average	1.30
		Std Dev.	0.08

Extrapolating the decrease of the felt flow rate from the 4 ¾” piece to a felt width of 30ft is shown below. The relationship was assumed to be linear. A felt of 0.3958ft with 50% fingers has a flow rate of 1.3g/s. With the assumption of linearity, a felt width of 30ft will give a flow rate of 98.526g/s=1.56gpm.

4.75inch=	0.39583333	ft
Average flow rate	1.3	g/s
Flow rate for 30ft	98.5263158	g/s
Conversion	5911.57895	ml/min
Conversion	1.56184384	gpm

7.4.6 Experiment: Approximation of felt maximum absorption and drying time

Hypothesis:

The capillary mat (felt) will become fully saturated with water and reach maximum water content without dripping. The mat will then dry out on its own time. After the mat has dried out to a certain water content, the mat will no longer soak water anymore and becomes unusable to us.

Method:

Four separate equally sized mats were used. Mat one was used as a control mat and the other three were used to test the soaking issue at different drying times. The mats were hung off the table and the top was placed in a bucket of water. All the mats were soaked and re-soaked with the same amount of water at the designated times. All the mats were placed the same distance under water to get the same relative soaking.

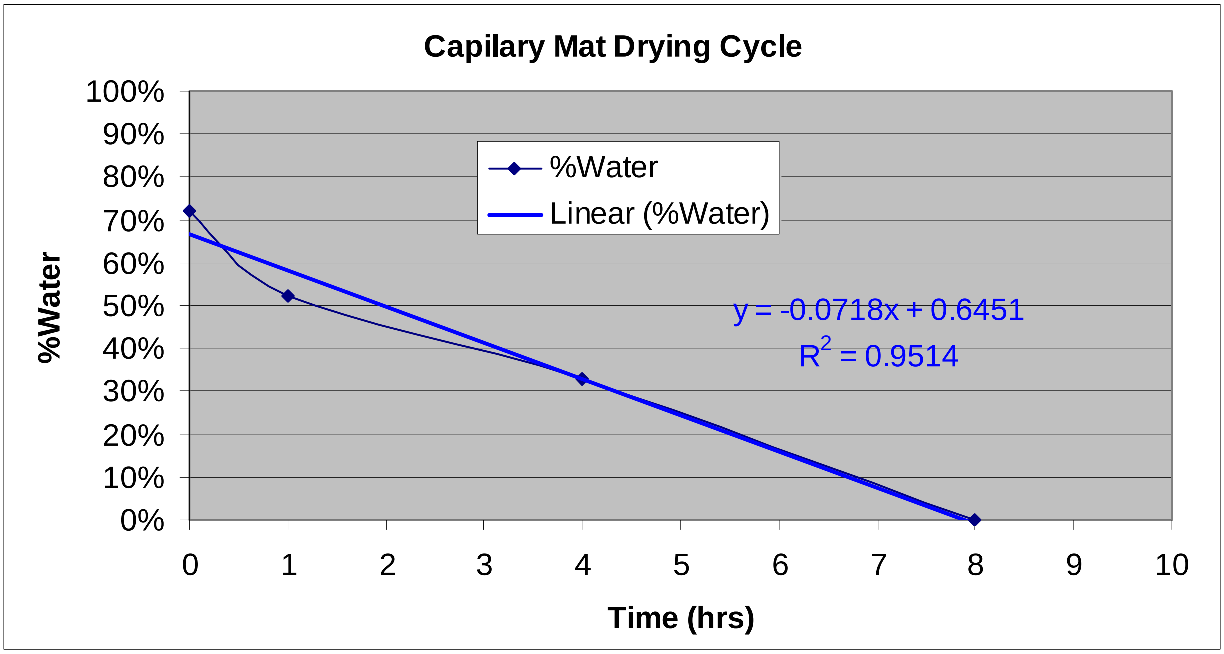
Materials: 4 x Capillary mats – each 5"wide by 40" long

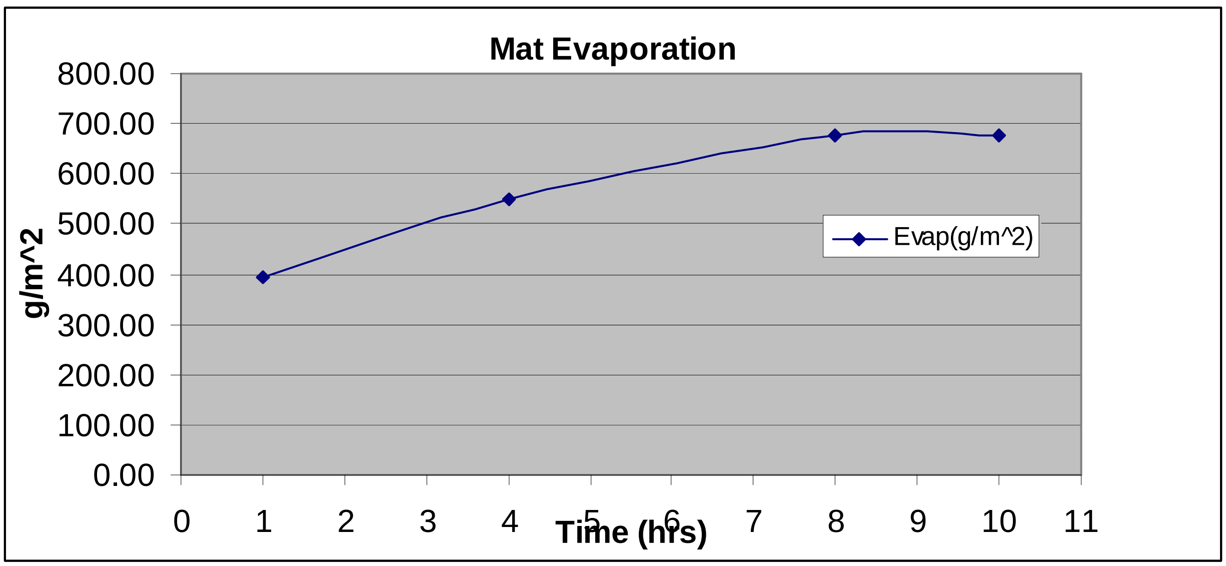
Data:

Time was started after the fully soaked mats stopped dripping water. Mat 1 was weighed dry at 33.5 g.

Mat 1 - Control Mat

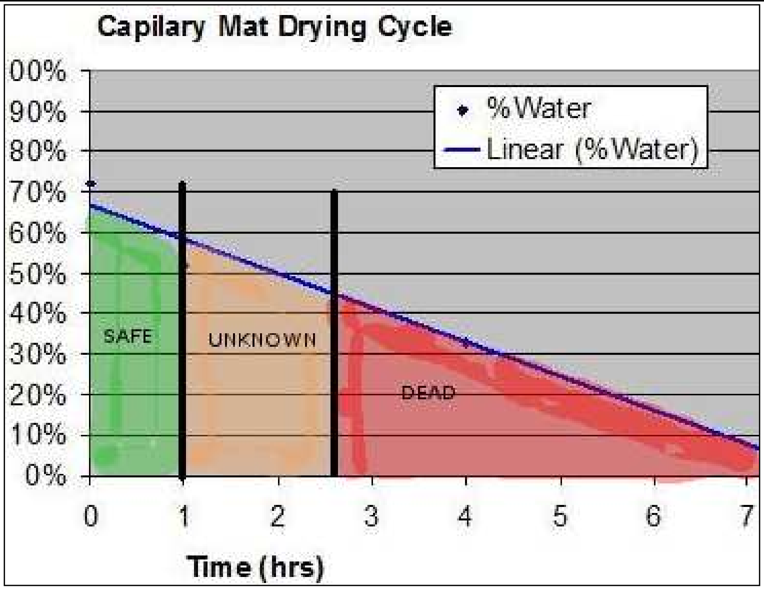
Time(hrs)	Weight(g)	%Water	Evap (g)	Evap(g/m^2)
0	120.8	72%	0.00	
1	70	52%	50.80	393.19
4	50	33%	70.80	547.99
8	33.6	0%	87.30	675.70
10	33.7	0%	87.30	675.70





Observations:

It was observed that the mat would accept full soaking after 1 hour of drying however the mat would not soak after 2.5 hours of drying. Therefore the critical value of drying time exists between 1 and 2.5 hours under standard conditions. To be safe, we would conclude a limit of 1 hour of drying time is set before the mat needs to be re-evaluated. The mat held a maximum of 72% water by weight and dropped to 52% after 1 hour. So once the mat has been fully soaked, it needs to be at least 50% water by weight to prevent dry out.



Calculations:

Percent water was calculated by subtracting the dry weight off the measure totals.

% water (by weight) = $\dfrac{W - Wdry}{W}$

Evaporation per metre squared of mat can be estimated by finding the weight of water lost during the time interval.

Evaporation (g/m^2) = $[W_{max} - W_{t=1hr}] \div [5 \text{ in x } 40 \text{ in}] \text{x} [12 \text{ in/ft}]^2 \text{x} [3.28 \text{ ft/m}]^2$

Our data gives approximately 400 g/m^2 of water evaporated in the first hour for any size mat under standard room conditions. The graph levels off just under 700 g/m^2 which is our mat absorption value. Water absorption per metre squared of mat can be found in a similar way

Absorption (g/m^2) = $[W_{max} - W_{dry}] \div [5 \text{ in x } 40 \text{ in}] \text{x} [12 \text{ in/ft}]^2 \text{x} [3.28 \text{ ft/m}]^2$

Our data gives approximately 700 g/m^2 of maximum water absorption for any sized mat under standard room conditions.

Conclusion:

We determined the capillary mat can hold a maximum of 72% water by weight. If this value drops to 50% water by weight, the mat needs to be soaked again. If the mat continues to dry out, test need to be done to decide whether the mat is still usable. 700 g/m^2 can be used to approximate how much water any sized mat will absorb without dripping. Also, we notice it takes about 8 hours for the mat to completely dry out.

7.4.7 Experiment: Approximation of water content in soil and soil drying times

Hypothesis:

Plants are watered until they are fully saturated without dripping water. The weight of the plant is measured at the beginning and intervals over a week. The plant should be completely dried out and said to be dead in a week.

Materials:

Scale, one large plant in a container, four small plants in a container

Observations:

The plants showed signs of being dried out after three days, however they still held some water. They were visibly dying after five days and dead after seven.

Data:

Big Plant

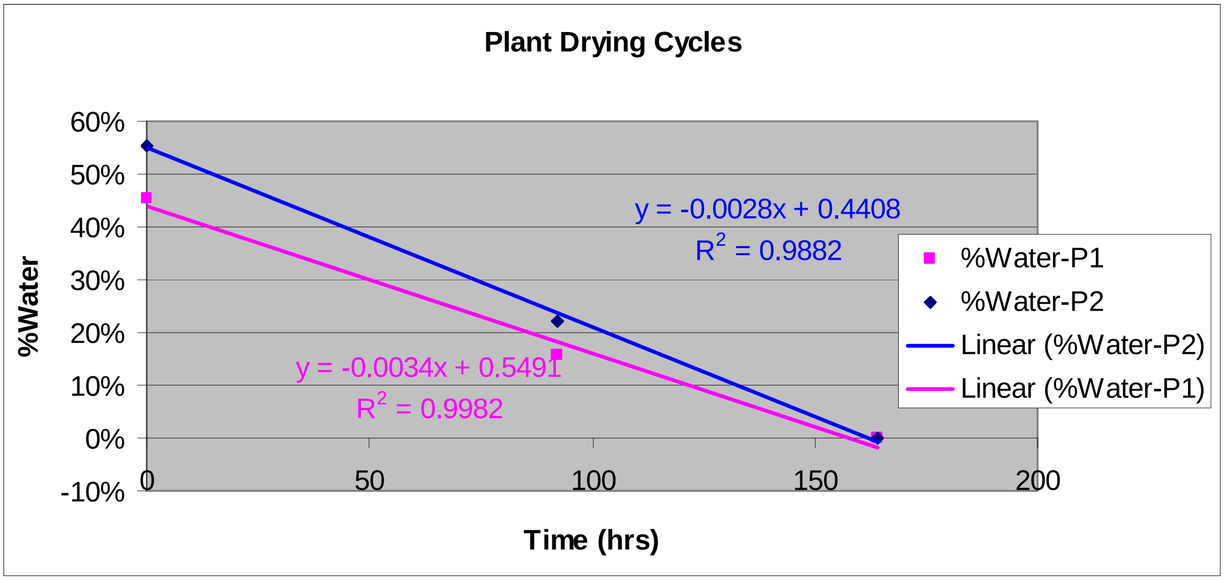
Container 27 g

time(hrs)	Tot W(g)	Plant W(g)	%Max	%Water
0	285	258	1	45%
92	194	167	0.647287	16%
164	168	141	0.546512	0%

Little Plant

Container 12 g

time(hrs)	Tot W(g)	Plant W(g)	%Max	%Water
0	302	290	1	56%
92	193	166	0.572414	22%
164	156	129	0.444828	0%



Calculations:

Percent water in the soil is found by subtracting the dry weight which was measured after seven days of drying.

% water (by weight) = $\dfrac{W - Wdry}{W}$

We can get a rough estimate on how much water is evaporated per hour using the equation

$$[\%water(t1) - \%water(to)] \div [t1 - to]$$

Plant 1

to→t1 = 0.31% water per hour
t1→t2 = 0.22% water per hour
to→t2 = 0.27% water per hour

Plant 2

to→t1 = 0.36% water per hour
t1→t2 = 0.30% water per hour
to→t2 = 0.27% water per hour

Average = 0.28% water content by weight of the soil per hour is lost due to evaporation

Conclusion:

The plants hold about 45-55% water by weight when fully saturated and not dripping or pooling. Therefore a fully watered plant can be assumed to be in this range of saturation. Over time, we can approximate the soil moisture content by weight by using the graphs or using the average calculated at 0.28% water content lost per hour.

7.4.8 Trough Sizing Calculations

Starting off with our known values of water content in saturated soil, as well as the rate of water loss from the soil, we can determine the required size of the trough.

Water content, by weight percentage, of saturated soil: 55%
Water loss per hour: 0.28% of the original water content

Setting a watering rate of once per hour and using the overall size of the wall, we determine the amount of water required each hour:

Area of wall = 30' x 36' = 1080ft^2 = ~100m^2
Depth of soil = 8cm = 0.08m
Total volume of soil on the wall = 8m^3

Density of saturated soil = 3530lbs per m^3

Total weight of saturated soil on wall = 28334lbs
Total weight of water on wall = 28334lbs x 55% = 15584lbs

Required amount of water per hour = 15584lbs x 0.28% = 43.6lbs per hour = 19.8kg/hr = 19.8L/hr

For a 30 foot trough, we will need at least 19.8L of capacity

Water volume per length of trough = 19.8L / 30ft = 0.66L/ft = 4.92L/m = ~5L/m = 0.005m^3/m

Taking a water depth of 2 inches, we come out with a required trough width of approximately 10cm. In order to ensure there is no spillage, another 0.5 inches is added to the trough depth.

Final cross sectional dimensions of upper trough: 2.5" depth x 10cm width x 30ft length

For the bottom trough, we simply double the depth of the trough on top, so we require a 5" depth for the water. In order to ensure there is no spillage, as well as a sufficient water depth to allow proper pumping, we add an inch to the depth.

Final cross sectional dimensions of bottom trough: 6" depth x 10cm width x 30ft length

7.5 FMEA Table

Classification	Function	Failure mode	Effects	S (severity rating)	Cause(s)	O (occurrence rating)	Current controls	D (detection rating)	RPN (risk priority #)
A.1	Irrigation	Recycling pump breaks down	Water fills up in the bottom trough and eventually overfills onto the floor	4	Mechanical failure of pump, pump gets clogged	3	Monthly inspection of all mechanical components	4	48
A.2	Irrigation	Valve at the top of the system gets stuck off	Plants do not receive any water and eventually die	7	Mechanical failure of valve	3	Low level sensor alarm, monthly inspection of all mechanical components	2	42
A.3	Irrigation	Low level sensor does not trip for top trough	Plants do not receive any water and eventually die	7	Level sensor failed or disconnected	3	Timer for filling up trough, monthly inspection of all mechanical components	2	42
A.4	Irrigation	Valve at the top of the system gets stuck on	Water spills over top trough and onto the atrium floor	4	Mechanical failure of valve	3	High Level sensor alarm, monthly inspection of all mechanical components	2	24
A.5	Irrigation	High Level sensor does not trip for top trough	Water spills over top trough and onto atrium floor	4	Level sensor failed or disconnected	3	Physical daily inspections of living wall, monthly mechanical component inspections	2	24
A.6	Irrigation	High Level sensor does not trip for bottom trough	Water spills over bottom trough and soaks floor	4	Level sensor failed or disconnected	3	Physical daily inspections of living wall, monthly inspection of all mechanical components	2	24
A.7	Irrigation	Felt rips or is not properly attached to a cell	Vegetation will dry and eventually die	6	Improper assembly, interference with felt from a bystander	1	Monthly physcial inspection of felt	4	24

B.1	Structure	Living wall skeleton structure to structural wall connections break	Living wall breaks and falls onto the atrium floor	9	Extra loading on living wall, improper assembly	1	Daily physical inspections	8	72
B.2	Structure	Structural Beam (vertical or horizontal) collapses	Some or all of the cells break off the skeleton.	8	Extra loading on a specific beam	1	Daily physical inspections	8	64
B.3	Structure	Bolt connecting cell to skeleton structure comes loose	Cell falls off wall onto atrium floor, possibly killing vegetation	7	Improper assembly, extra loading on cell	1	Daily physical inspections	7	49
B.4	Structure	Structural Beam (vertical or horizontal) rust	Beam could break off, bringing down with it a cell[s] destroying the vegetation within the cell[s]	7	Water on a structural beam over a long period of time	2	Periodic inspection of structural beams for rust.	3	42
B.5	Structure	Rotational pin for a cell[s] breaks	Cell has the possibility of rotating around its center.	2	Extra loading on cell, interference from a bystander	1	Daily physical inspections	7	14
C.1	Vegetation	Garden soxx is not in the correct position to touch the felt	The vegetation does not soak up water and eventually dries out and dies.	6	Improper assembly, interference from a bystander	1	Daily physical inspections	6	36
C.2	Vegetation	Garden soxx falls out of cell	Garden soxx and vegetation falls to the atrium floor.	6	Improper attachment, interference from a bystander	1	Daily physical inspections	3	18
C.3	Vegetation	Plant falls out of garden soxx	Plant falls to the atrium floor and dies	6	Plant grows to large, interference from a bystander	1	Daily physical inspections	3	18

Appendix N Acknowledgements

This project would not have been possible without the input and knowledge of several people. The following persons have contributed to the project and may or may not be available for further assistance.

Liska Richer (client)
Coordinator, SEEDS Program
UBC Campus Sustainability Office
2329 West Mall
Vancouver, BC V6T 1Z4
Tel: 604-822-3270
Email: liska.richer@ubc.ca

Jensen Metchie (client)
Sub-Renewal Coordinator
UBC Alma Mater Society
6138 SUB Boulevard
Vancouver, BC V6T 1Z1
Email: subrenewal@ams.ubc.ca

Alex Marks
General Manager
Filtrexx International
35481 Grafton Eastern Rd
Grafton, OH 44044440-926-2607
440-926-4021 (fax)
Email: alexm@filtrexx.com
Web: www.filtrexx.com

David Kaplan
Greenhouse Technician
Horticultural Greenhouse
UBC Faculty of Agricultural Sciences
2357 Main Mall
Vancouver, BC V6T 1Z4
Tel: 604-822-3282
Email: dkplan@interchange.ubc.ca

Douglas Justice
Associate Director / Curator of Collections
UBC Faculty of Land & Food Systems
6804 SW Marine Drive
Vancouver BC V6T 1Z4
Tel: 604-690-4405
Email: douglas.justice@ubc.ca

Paul Winkelman
Mech 457 Advisor / Sessional Instructor
UBC Department of Mechanical Engineering
2054-6250 Applied Science Lane
Vancouver, BC V6T 1Zt
Tel: 604-822-2805
Email: pwink@interchange.ubc.ca

Louise St. Pierre
Associate Professor &
Assistant Dean of Industrial Design
Faculty of Design + Dynamic Media
Emily Carr University of Art + Design
1399 Johnston Street
Vancouver, BC V6H 3R9
Tel: 604-844-3800
Email: lsp@ecuad.ca

Eugenia Bertulis
Sessional Faculty
Faculty of Design + Dynamic Media
Emily Carr University of Art + Design
1399 Johnston Street
Vancouver, BC V6H 3R9
Tel: 604-844-3800
Email: ebertulis@ecuad.ca

Appendix O   Project Reflections

Stephanie Wilson

While I have participated in design projects before, this was the most difficult. Major challenges included the team`s lack of expertise in green systems, vegetation and vegetation requirements, and living walls in general. Without the contributions of many people, this project would not have been possible. I also found that we had a strongly-opinionated team, which presented it`s own challenges along the way. The most significant turning point was the decision to eliminate two initially identified sub-functions: monitoring and ventilation. This significantly reduced the scope of the project to make it more manageable. To future students, I would strongly recommend that a few manageable project goals are identified early in the project, and that these are the focus of the project; as opposed to several large goals which may not be completed.

Brittany Hilbrecht

One of the main things I have learned during this capstone project is to talk to your supervisor and determine how your project fits with the report requirements and where it doesn't. We spent a lot of wasted time trying to mould our project to fit the requirements of the reports; when our instructor was looking to mark us on how our project was different and what we felt was important to include in the reports and not specifically on the requirements. Another key thing is to talk to your clients early and regularly, through meetings with our clients we came up with important contacts at UBC like Douglas and David at the horticultural center that made a huge contribution to our project.

A major turning point for our project was when we decided to no longer use expensive sensors to test our water content and use a capillary mat to control the water intake to each cell. This idea not only provided a cheaper solution to our wall but a new innovative idea that we could test and use as our own. There are several things I might do differently looking back, but the major thing would be to define the scope of the project EARLY. We found half way through that our scope was way too large, and the time and resources left would not be sufficient to finish what we had intended.

Jordan Cowan

During the design of the Living Wall, we saw that five engineers, with the help of one industrial designer, could be creative and create something new. Everyone played a part with their own strengths and ideas. Seeking out advice from professors really helped guide the team and saved us a lot of time. Next time, we could examine existing designs more closely and perhaps even try and replicate them to see where they could be improved.

Wilson Tran

In doing the Living Wall design project, I have learnt that it is very important to determine the right balance between planning and getting work done. If not enough planning is involved, the work would not be done right. If too much time is spent planning, then there wouldn't be enough time to complete the work. It is also very important to spend time to consult experts within the field to get a good step into a project that you aren't at all familiar with. Key turning points included speaking with Douglas Justice, and prototype testing for the originally planned ventilation system. If I could do it again, I would first have consulted some experts in person before attempting any concept development, so we had an idea of what is out there. My best recommendation for future students it to make sure you're familiarized with what you're trying to deal with, before you start the design.

Wen Li

Upon looking back at the design process, I realized the importance of sticking to simple solutions and having better understanding on existing products, design and experience, before seeking innovative ideas. Especially when exploring fields (i.e.: horticulture) where the team has little knowledge on, the practical advices from experts had been extremely helpful. On the other hand, the team has demonstrated impressive level of organization and initiative throughout the terms. As a result, we were able to come up with numerous empirical data from well-planned testing, wonderful looking prototypes and quality reports.

Jacky Ling

As an industrial design student from Emily Carr University joining the engineering team, I found my participation in this project greatly influenced by my peers. This project has brought together the best of each team member in areas of concept, analysis, and prototype. Though there were shortcoming in our lack of knowledge in sustainable living wall systems and its components, we were able to overcome these obstacles through consultation with experts in the respective field and the exploration of the breathe of options and material choices. Of the many challenges I have encountered, one that stood out was the range of ambitious goals set in the early stages of the project. Even though the range of goals has allowed us to explore the myriad of fresh ideas for a creative and forward thinking project, it has also hindered our progress on focusing the project as a whole rather than focusing on each sub-systems individually. I found the project to be a great example of an immersive collaborative experience. It is especially rewarding as our project bridges science and nature, academia and professionals, and students of two institutions.

Appendix P References

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